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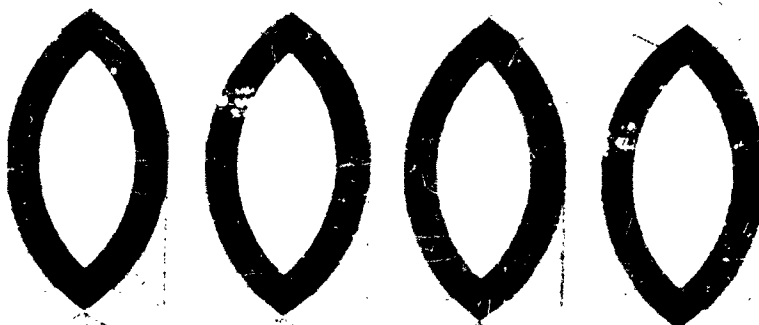
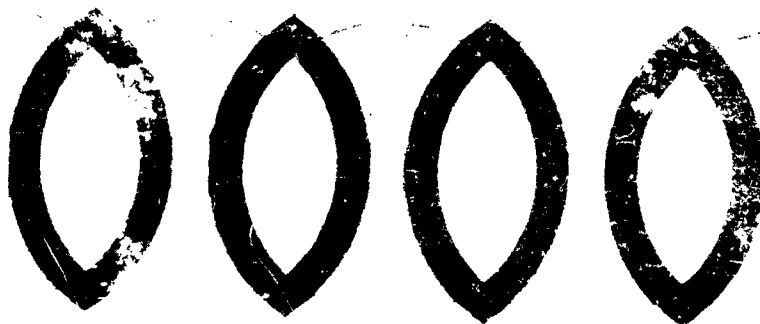
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**History  
And  
Progress  
of  
AFCRL**

JANUARY 1961 — JUNE 1962



A DETAILED  
SURVEY OF  
RESEARCH AT

**THE AIR FORCE CAMBRIDGE  
RESEARCH LABORATORIES  
OFFICE OF  
AEROSPACE RESEARCH  
BEDFORD MASSACHUSETTS  
OCTOBER 1962**



### **Foreword**

This volume constitutes the first annual unclassified report of the Air Force Cambridge Research Laboratories. It replaces narratives previously published separately by the organization's Electronics and Geophysics Research Directorates. Although it is considered the fiscal year 1962 report, it has been expanded to cover the 18-month period from 1 January 1961. Its purpose is to provide military and civilian agencies unclassified information on the scope and progress of the Laboratories' in-house research programs. Important classified projects are consequently omitted and will be treated in a separate report planned for later publication. This narrative was written and edited by Mr. Carl Berger, AF-CRL historian, assisted by Mr. LaVerne E. Woods, Chief of the Research Information Office. It is based on material submitted by the individual laboratory chiefs, plus technical and staff papers and memorandum, and project documentation.



B. G. HOLZMAN  
Brigadier General, USAF  
Commander

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**Q** The Air Force Cambridge Research Laboratories, a scientific community of nearly 1100 personnel with headquarters at Laurence G. Hanscom Field near Boston, have the mission of conducting basic and applied research for the Air Force in electronics and geophysics. AFCRL scientists are personally engaged in research on almost every aspect of physical phenomena. Their work covers physics, chemistry, mathematics, biology, electronics, meteorology, engineering and astronomy. The tools they bring to bear on their studies include the latest available to science: from instrumented rockets and earth-orbiting satellites to radio telescopes and particle accelerators. The end objective of all their research, whether concerned with the atomic lattice structure of semiconductor materials or the effects of solar radiations on manned and unmanned space operations, is the discovery of new scientific knowledge which will contribute to future Air Force advances in operational techniques and equipments.

**ORGANIZATIONAL HISTORY:  
A BRIEF REVIEW**

During the period a major AFCRL reorganization was accomplished which gave the Laboratories "a single voice" for the first time since the early post-war years. This event involved the consolidation of staff and logistical support functions previously performed separately within the two research directorates.

AFCRL's organizational story goes back to September 1945 when the ances-

tral unit, the Cambridge Field Station,\* was established by the Air Technical Service Command. An Electronics Research Directorate (ERD) eventually emerged, drawing its elements from the famous Radiation Lab of M.I.T. and the Harvard Radio Research Laboratory — wartime organizations which made important contributions to the development of radar and electronic counter-measures. Not until three years later, in 1948, did elements of what later became the Geophysics Research Directorate (GRD), join the Cambridge unit. They originated in an atmospheric research group of the Air Force's Watson Laboratories at Red Bank, New Jersey.

The dissimilar beginnings of the directorates, plus research programs seemingly distinct and unrelated, led to the growth of separate administrative staffs, working under the name of the Air Force Cambridge Research Laboratories.\*\* They supervised the activities of their laboratory elements located in different facilities in the Boston-Cambridge area. The two directorates continued to function on a largely autonomous basis throughout the entire decade (1951-1961) they were assigned to the Air Research and Development Command (ARDC).

Early in the ARDC period a number of important external changes took place, resulting in redesignation of the organization as the Air Force Cambridge Research Center. The latter came in to embrace not only a dozen electronics and geophysics laboratories, which became more and more involved in systems development work during the Korean

War, but also a short-lived Atomic Warfare Directorate; an Operational Applications Laboratory; the Lincoln Project Office (air defense); and a supporting Wing at Hanscom Field.

Construction of permanent facilities at Hanscom Field did not begin until October 1952. The first laboratory building was accepted in April 1954, and during the next several years and as late as March 1962, elements of the organization continued to move from their temporary quarters to the Hanscom complex. (A brief description of facilities is provided below.)

In the spring of 1960 the first of a series of major ARDC reorganizations led to the separation of the Laboratories' work from systems developmental activity. A new unit was created at Hanscom Field, today known as the Electronics Systems Division of the Air Force Systems Command,\* and assigned responsibility for development and integration of electronic command and control systems. The Center was dissolved and the laboratories, although still part of ARDC, became a tenant unit at Hanscom Field, "cut loose" to return to the original mission of basic and applied electronics and geophysics research.\*\*

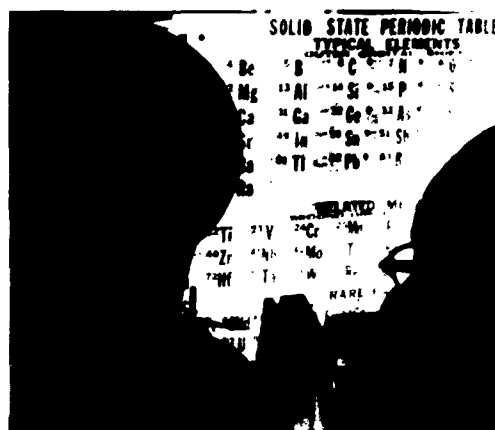
These changes left AFCRL's dual management structure largely intact. However, in April 1961 a new situation arose with the establishment of the Office of Aerospace Research (OAR), a new command under Major General Daniel E. Hooks, in Washington, D. C. The creation of OAR (its predecessor was the Air Force Research Division)

\* Originally created to recruit scientists for peacetime employment at Air Force facilities in Ohio and New Jersey.

\*\* The AFCRL designation became effective 4 July 1949.

\* ARDC was reorganized and redesignated as the Systems Command on 1 April 1961.

\*\* For five months during 1960 the laboratories were known as Detachment 1, Air Force Research Division.



People, equipment and facilities are the basic elements of an organization. In a research organization, people assume the dominant and critical role.

completed the separation of basic aerospace research from systems developmental work. OAR was made responsible for planning, programming and managing the Air Force's basic research program; AFCRL transferred to it to become the largest single subordinate command.

The effects of this change were soon felt at Hanscom Field when the small AFCRL staff under Brigadier General B. G. Holzman,\* was forced to assume certain administrative responsibilities for 200 assigned military personnel (95 officers, 105 airmen) — functions previously performed for it by the Electronic Systems Division. This event was one aspect of the internal realignments that followed.

Another, and more important, involved a general review of the organization's management structure by General Holzman. During his first 10 months as commander, General Holzman had become increasingly concerned over the two-headed administration of the laboratories. He noted that while the classical separation between electronics and geophysics had considerably narrowed and in some cases overlapped, the directorates continued to function in near-isolation from one another. Each had developed different methods of preparing and submitting annual budget requests; each had dissimilar procedures for seeking logistic support; and each had differing publication programs. The commander became convinced that in the programming area in particular the time had come for centralized management.

\* General Holzman assumed command on 24 September 1960. A graduate of the California Institute of Technology, General Holzman has been associated with Air Force research and development throughout his military career. For the past several years he has directed the work of various Air Force agencies conducting basic and applied research.

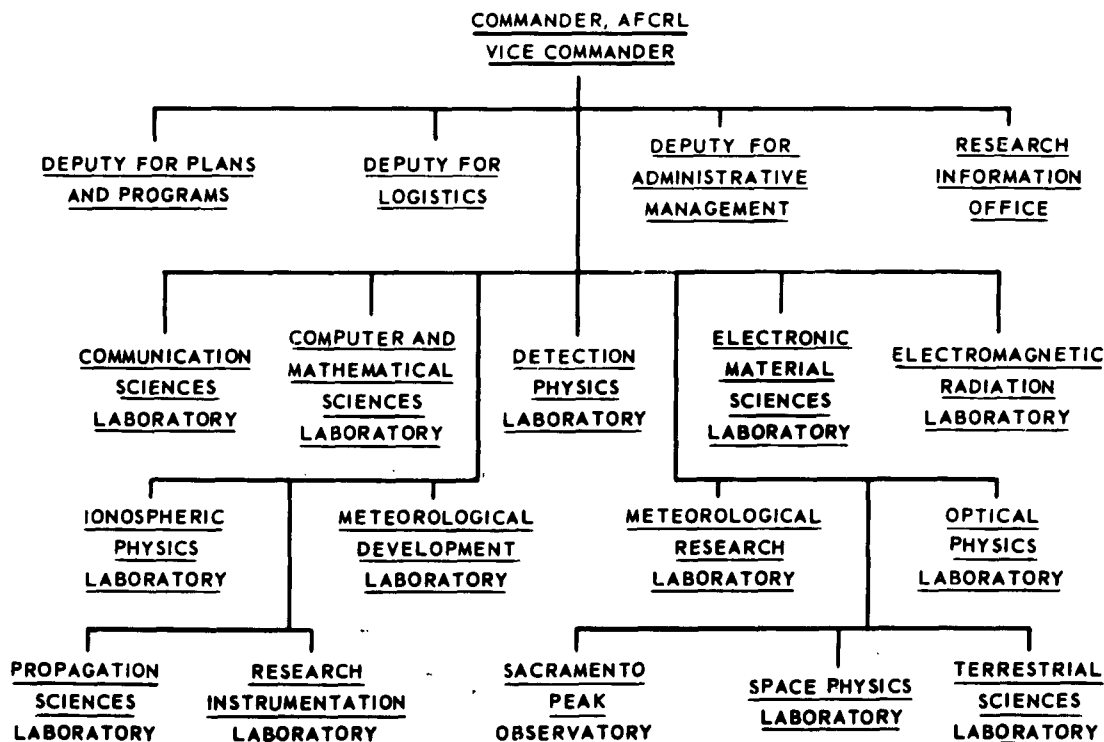
As a result of this organizational review, which was discussed with officials in Washington, the Office of Aerospace Research on 1 September directed General Holzman "to consolidate administrative, logistics and programming functions" within his headquarters. Subsequently, the commander appointed a task force of key personnel to work up a detailed plan. On September 1961 General Holzman also addressed a meeting of laboratory and staff personnel to explain the reasons for the impending consolidation, and dispel any concern that might have arisen over the changes. He reviewed several of the administrative problems he had encountered, and the weaknesses flowing from the two-sided organizational structure.

In late September the special task force drew a consolidation plan which, with some modifications, was adopted. Effective 9 October 1961 five major staff

and support elements were established under Headquarters AFCRL—for plans and programs, logistics, administrative management, technical services and research information. Personnel to man these offices were drawn largely from the separate directorate programming and management divisions, which were eliminated. The heads of the directorates\* continued to serve in those positions, being responsible for providing scientific advice on all research matters to the commander and to the AFCRL scientists.

The heart of the organization, the research laboratories, continued to

\* The ERD Director, Dr. L. M. Hollingsworth, Ph.D. in electrical engineering, has served in that position since 1955. Col. E. M. Douthett, Ph.D. in nuclear chemistry, was designated GRD Director on 13 November 1961. He replaced Col. E. A. Pinson, Ph.D. in nuclear physics and medical physiology, who was named Vice Commander of the Laboratories.



function with only minor changes and consolidations. They consist of 14 laboratories: Communication Sciences; Propagation Sciences; Computer and Mathematical Sciences; Detection Physics; Electronic Material Sciences; Electromagnetic Radiation; Space Physics; Meteorological Research; Ionospheric Physics; Terrestrial Sciences; Meteorological Development; Optical Physics; Research Instrumentation; and the Sacramento Peak Observatory.

Organizational charts showing the present AFCRL structure will be found in an appendix to this report.

#### PERSONNEL

In June 1962 the command consisted of some 680 professional personnel, who constituted about 64 percent of the organization's total population. The competence of these personnel was reflected in the large number of advanced degrees they held: 101 Ph. Ds (94 civilian, 7 military), and 205 Masters (152 civilian, 53 military).

In the course of their work during 1961-1962 these personnel established scores of temporary field sites in all parts of the world. The results of their field investigations and laboratory research, and the advances they recorded, were subsequently reflected in 192 unclassified and classified scientific and technical reports published by AFCRL during the 18-month period. In addition to these reports, the scientists during the same period wrote and published some 330 papers and articles in the professional literature — another important product of their research efforts.

A third aspect of their work during the 1961-1962 period involved various federally-sponsored and non-federal scientific and professional meetings held in Europe, the Middle East and Asia as well as in North America. At several hundred conferences ranging from the



The principal AFCRL laboratories are located at L. G. Hanscom Field near Bedford, Mass.

“International Conference on Cosmic Rays” in Kyoto, Japan, to the “Symposium on Electromagnetic Theory and Antennas” in Copenhagen, Denmark, AFCRL personnel presented 294 scientific and technical papers. A complete list of these presentations, plus lists of AFCRL technical reports and professional articles published, will be found in the appendices of this volume.

Throughout the period AFCRL scientists served as consultants and technical advisers to other government and non-government agencies, and, indeed, this advisory function was an intrinsic part of the AFCRL mission. While representing the Air Force on numerous permanent defense committees, they also gave important scientific information and guidance (on ad hoc bases) to such agencies as the National Aeronautics and Space Administration, the U. S. Weather Bureau, the Defense Atomic Support Agency, and the Atomic Energy Commission. They were called upon for advice and guidance by such industrial



concerns as Boeing and General Electric, and by members of the North Atlantic Treaty Organization. Several scientists lectured at various American universities, including Harvard, Yale, Brandeis and M.I.T., and several served as visiting professors to West German and Israeli universities.

Besides these activities, AFCRL personnel monitored and supervised a multi-million dollar contract program (see below) that encompassed hundreds of American universities, industrial organizations and private research agencies. These contracts, most of them in direct support of larger programs conducted within the Laboratories, were an important means of supplementing the in-house research programs.

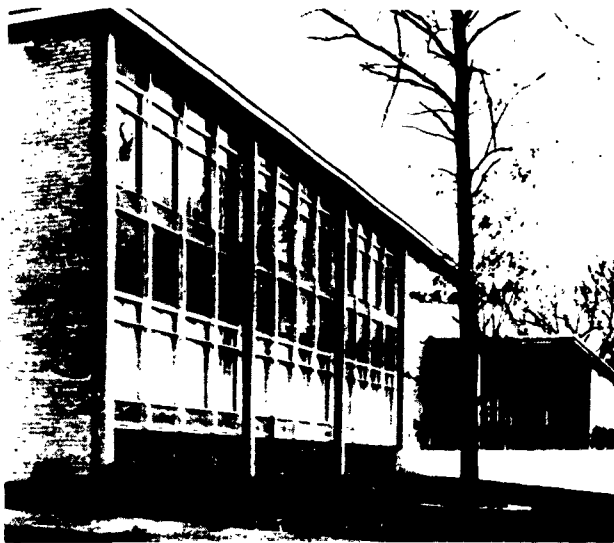
The sponsorship and conduct of international scientific conferences was another integral part of personnel activities during the period. In February

1961 AFCRL was host to 125 scientists from half-a-dozen countries, who met to review data obtained from a single unusually large solar flare that occurred the previous November. In April 1961 AFCRL sponsored the first International Conference on Ultrapurification of Semiconductor Materials, a highly-successful meeting held in Boston and attended by more than 500 persons representing 11 countries. The organization also sponsored a National Symposium on Winds for Aerospace Vehicle Design in September 1961; the Second International Conference on Exploding Wire Phenomena, in November 1961; the Second Symposium on the Plasma Sheath in April 1962; and a number of other conferences attended by hundreds of scientists from throughout the world. AFCRL personnel from the various laboratories not only organized these important conferences, but also chaired numerous sessions, presented research papers, and later served as editors of the various published Proceedings.

#### FACILITIES AND FIELD SITES

The bulk of AFCRL's research facilities are located at Hanscom Field, about 15 miles from Boston. Consisting of some 19 major structures, they include separate buildings for solid state materials research, digital communications, infra-red physics, hydromagnetics, meteorological equipment testing, irradiation studies, and the AFCRL Research Library. The latter is a half-million dollar structure completed in 1961. One of the largest of its kind in the nation, the library contains some 200,000 technical reports, 95,000 serials and 75,000 monographs.

In February 1962 AFCRL also occupied a new Solid Physics Building, which when fully equipped will provide the Air Force the finest facility in the free world for research into the basic mechanisms

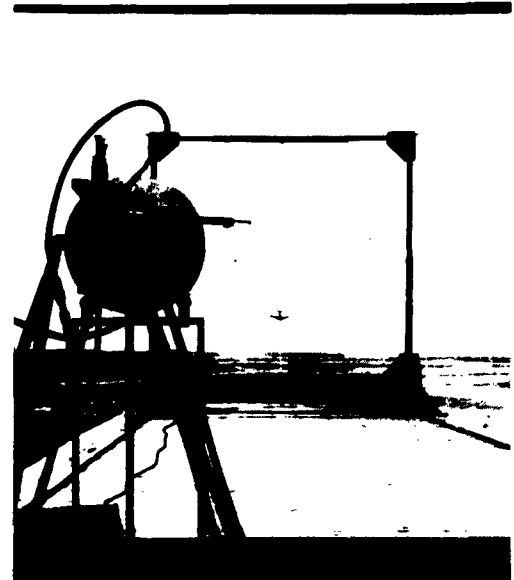


The AFCRL Research Library contains more than 75,000 monographs and over 200,000 technical documents. It is one of the finest technical libraries in the country for electronics and geophysics research.

of crystal growth and growth of electronically-active materials. Another important structure, scheduled for completion in October 1962, will permit AFCRL to bring together its diverse research activities in ionized gases and magnetohydrodynamics.

In addition to the above facilities, AFCRL maintains a number of permanent field sites in eastern Massachusetts — at Plum Island, Ipswich, Hamilton, Maynard, Mt. Wachusett, Prospect Hill, Oak Hill and Strawberry Hill. These permanent sites are used for research into the absorption and reflection characteristics of the aurora, antenna design and ionospheric disturbances; and for weather radar investigations and radio astronomy research. In the far west AFCRL also maintains one of the most complete solar observatories in the world, at Sacramento Peak, New Mexico. At Flagstaff, Arizona, scientists are engaged in cloud physics studies while at Holloman AFB in New Mexico and at Chico, California, AFCRL maintains balloon launch facilities that will help maintain the organization's stature as the leading center for balloon technology in the Department of Defense.

Besides these permanent facilities, numerous temporary or semi-permanent sites were set up during the period by AFCRL personnel. The latter included sites north of the Arctic Circle and in the South Pacific, and many sites associated with the 1962 series of U. S. atomic tests in which 60 AFCRL personnel participated. The nation's missile ranges also were used to launch numerous AFCRL experiments into outer space, carried piggy-back on Air Force ICBMs and satellites. In addition, AFCRL scientists launched several dozen of their own research sounding rockets carrying various geophysical and electronic experiments.



Among the 19 major facilities operated by AFCRL are the Ipswich Antenna Range and the Plum Island site, both located in eastern Massachusetts. At the Ipswich Range experimental antennas are tested and radar cross-sections of model missile shapes and aircraft are measured. At Plum Island, AFCRL conducts experiments concerned with auroral reflection and absorption.

### FINANCIAL RESOURCES

During fiscal year 1962, for the operation of the Laboratories, the command received approximately \$12.9 million. Slightly over \$8.5 million of that sum was for the pay of civilian personnel. During the fiscal year AFCRL also received a total of \$53.5 million in contract funds. Eleven million dollars was received from the Electronics Systems Division and nine million from OAR, both sums for work in areas of applied research; while slightly over \$10 million was received from OAR for the Laboratories' basic research activities. In addition, \$23 million was received from several other commands, such as the Defense Atomic Support Agency (\$9.6 million), the Advanced Research Projects Agency (\$6.1 million), the Space Systems Division (\$2.6 million). Slightly over 100 thousand dollars was received from NASA for the support of AFCRL-designed experiments, to be flown on future NASA satellites and deep-space probes.

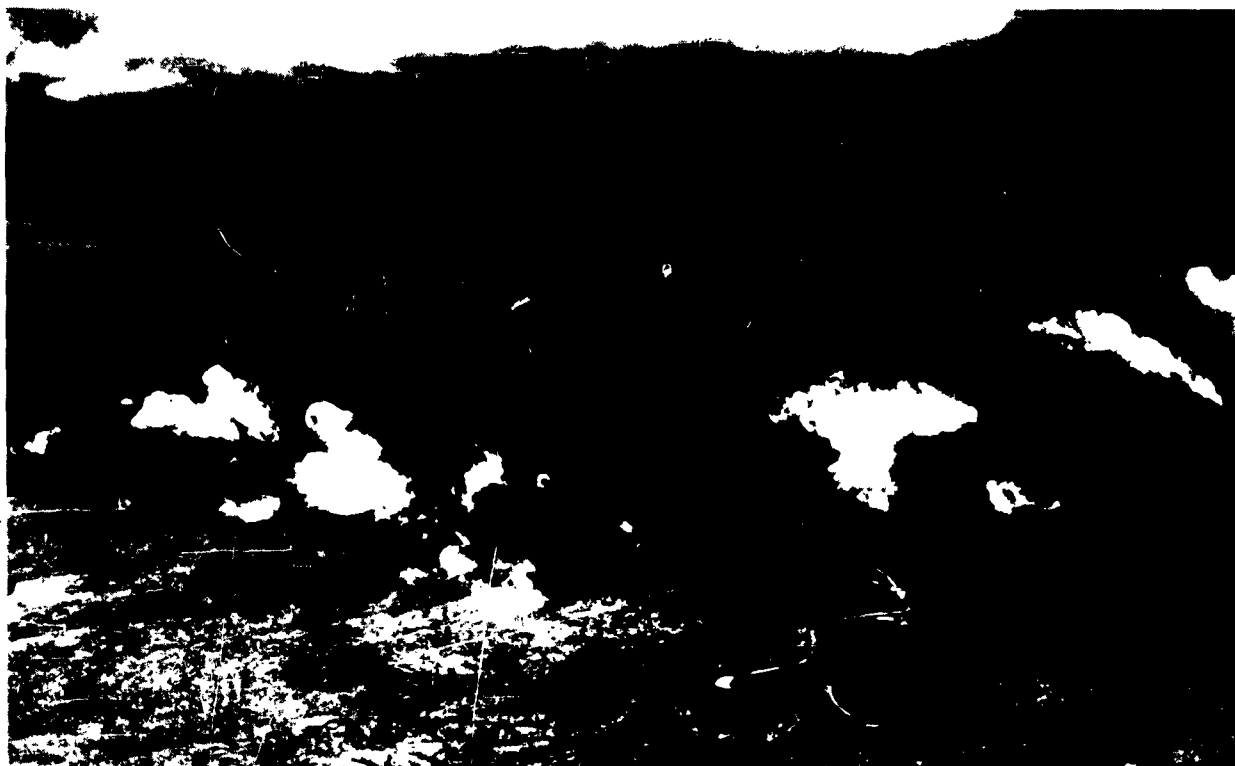
The most characteristic use of the contract funds made available to AFCRL was to support the in-house programs. This support ranged from direct work for the Laboratories (such as computation services, fabrication of rocket payloads, operation of field sites, etc.) to complementary or supplementary research carried out most characteristically in the universities but also by private industry. These funds went to support more than 1,200 active AFCRL contracts: 613 with universities, 496 with industrial organizations, 54 with non-profit concerns, and 44 with other government agencies. One hundred and fifty of these relatively small contracts were with overseas universities and organizations.

Together with the advances made by the in-house programs, the contractor contributions helped forward the work



AFCRL research may center around an instrumented rocket launched in the Arctic twilight—or it may center around a blackboard abstraction. Chalk consumption at AFCRL is relatively high.

of the Air Force Cambridge Research Laboratories. During 1961-1962 together they produced new and important scientific data and equipments which held promise of immediate as well as future Air Force advances in operational techniques and hardware. The story of the organization's research progress, with emphasis on the in-house programs, is narrated in the chapters that follow.



An isolated thunderstorm with its rapid spreading anvil is photographed by an AFCRL aircraft over Oklahoma.

**Q** For many years the Air Force Cambridge Research Laboratories have conducted wide-ranging meteorological investigations affecting almost every phase of Air Force operations. AFCRL's mission in this area, in cooperation with other military and civilian agencies, is the accumulation of new knowledge of the entire gaseous envelope of the Earth—its variations in pressure, temperature, composition and circulation. One of its ultimate goals is a detailed understanding of the factors that affect the weather, which may lead to a capability to accurately predict it, and perhaps to control it on a limited scale.

During 1961-1962 in-house studies conducted mainly by scientists of the Meteorological Research and Meteorological Development Laboratories produced a steady flow of important scientific data. These included new knowledge of atmospheric diffusion and upper level densities that affect missile launch operations and warhead reentry. New techniques were developed during the period on how to dissipate super-cooled stratus and above-freezing fog. In related areas, two AFCRL equipment programs were climaxed by installation of an automatic meteorological station and development of a new high altitude meteorological rocket sounding system.

In their pursuit of new knowledge of the atmosphere, the scientists used a variety of electrical and meteorological networks, including specialized ground and airborne radars, earth satellites, an instrumented television tower, sounding balloons and advanced sensing instruments. Laboratory personnel also uti-

lized a number of highly-instrumented aircraft, including a U-2, B-47, C-130, F-100F, T-33 and a Stearman crop duster. The story of the research programs, and advances made during the period, is narrated below.

#### **SMALL-SCALE WEATHER MODIFICATION**

The capability to modify local weather conditions obviously would be of great assistance in facilitating Air Force operations. Specific military applications would include clearing fog and stratus over allied airfields and missile launch sites to permit unrestricted operations, and clearing fog and stratus over enemy areas to permit photographic, visual and infrared reconnaissance, target selection and bomb damage assessment. The ability to modify the refractive index structure would help communications and missile tracking and guidance systems. The prevention or elimination of icing conditions on antennas would aid maximum performance at early warning sites.

**OPERATION PEA SOUP 1961:** During the reporting period AFCRL's weather modification program concentrated on warm (above freezing) fog and stratus, and supercooled (below freezing) fog and stratus. As part of the first research effort, Operation Pea Soup 1961 was conducted in the summer and fall months at Arcata, California. During one of Arcata's foggiest years of the last decade, scientists of the Meteorological Research Laboratory conducted almost 50 ground and airborne experiments, tested seven potential fog dispersal techniques, and collected 330 hours of fog data in the process.

In one series of successful dispersal experiments, carbon black was dropped from a Stearman crop duster aircraft on top of stratus approximately 600 feet thick at the rate of 60 pounds per

mile. No attempt was made to maintain the optimum carbon particle size of 0.1 micron diameter during the dispensing operation, and most of the particles reaching the cloud probably were larger by a factor of a hundred or more due to agglomeration. In each case an effect due to the seeding was observed, while in five tests several small clearings were produced in the seeded area through which the ocean was clearly discernible. Visually, the effect caused by the carbon seeding was a "churning" motion resembling turbulence.

The results of the carbon experiments indicated that whenever the distance between the cloud top and base of the inversion was small, on the order of 100 feet or less, the carbon particles became trapped, remained concentrated for relatively long periods of time and caused large observable effects. When the distance was greater, most of the carbon particles rose to the inversion level, thereby diluting the particle concentration and producing a lesser effect.

The experiments were considered especially significant in that they indicated there was a more complex sequence of events involved than had been previously considered. This was evident by the fact that larger effects were produced in stratus with far from ideal seeding conditions than could be predicted by theory, even for the optimum size. Previously investigators attributed the effect of the carbon simply to the heating of the droplets, which caused the evaporation. However, the AFCRL experiments indicated the heating also caused the cloudy air to rise and mix with drier, warmer air above which contributed to the evaporation.

Several of the Arcata experiments, in which surface active agents were used, also produced observable effects. Deep cuts and in some cases small

clearings were produced in stratus clouds when the surfactants—primarily surface tension depressants of the cationic, anionic and nonionic type—were sprayed over them from a Stearman aircraft. In experiments using calcium chloride and lithium chloride solutions sprayed both from the air on stratus and from the ground in fog, the effects produced were no greater than could be achieved with equivalent amounts of plain water. Water alone, it was found, produced a small observable and measurable effect, and therefore served as a control for all other liquids tested.

As its title suggests, Operation Pea Soup 1961 was a continuation of field tests conducted in prior years. In this connection, detailed analysis of data obtained in 1960 experiments revealed an extreme horizontal variability in the fog. These observed inhomogeneities could explain the non-reproducibility of effects for most dispersal techniques, and they underlined the need for knowing the drop-size distribution of the fog when selecting the technique to be used. To obtain this information, development of a refined instrument was initiated during 1961, which would continuously measure fog-drop size distributions with droplets of a diameter 10 microns and larger. AFCRL personnel, in the meantime, took steps in early 1962 to establish a new fog research site at Vandenberg Air Force Base, California, in continuation of their studies of warm fog and stratus dissipation.

#### **DISSIPATING SUPERCOOLED CLOUDS:**

The second important aspect of AFCRL's small-scale weather modification program was aimed at dissipating supercooled stratiform clouds and fog. The main goal was to provide the Air Force with the capability of economically dissipating supercooled clouds by a

self-contained seeding system carried aboard transport and cargo aircraft. During the fall of 1961 and in January 1962, AFCRL scientists demonstrated again, as they had in previous years, that such clouds could be dissipated by aircraft seeding with dry ice.

Their initial approach was to determine the most feasible method of making dry ice pellets directly from the expansion of liquid carbon dioxide. The basic process that was developed utilized a method of expanding liquid carbon dioxide through a nozzle into a cyclone separator. The gas phase was then vented overboard, and the solid carbon dioxide power centrifugally



Photo shows a typical hole created in a super-cooled cloud layer by dry ice seeding. Research was conducted over Goose Bay, Labrador in the fall of 1961.



separated and deposited on a moving belt which carried it to a pellet forming wheel. There it was compacted into dry-ice pellets of the proper size and at a rate needed for seeding. Dispersion from the aircraft was through a chute.

During the summer of 1961 an airborne prototype machine constructed under contract was installed in AFCRL's C-130 aircraft. Then, in late October and early November the machine was flight tested at Goose Air Base, Newfoundland. Six cloud seeding experiments were flown and conclusively demonstrated that the dry-ice pellets would effectively disperse supercooled cloud decks. The experiments, however, also uncovered a basic weakness in the machine. One deficiency was that 50 percent of the output was powdered dry ice, which was unsuitable for seeding purposes. Other related weaknesses were logistical in nature; that is, the problem of supplying enough dry ice.

As a result of these problems, the above testing was called off in order to enable the scientists to redesign the pellet-making machine to eliminate the deficiencies. This work was completed by 18 December and the modified machine was reinstalled aboard the C-130 for further test flights. In January 1962 new field experiments were again begun at Goose Air Base to determine the best pellet size, seeding rate and seeding pattern to use for all supercooled cloud conditions. Subsequently, final testing of the machine was held up because of higher priority requirements for the C-130; however, the program was expected to be completed before January 1963. In the interim, AFCRL personnel turned their attention to designing and developing operationally feasible methods of dissipating supercooled stratus and fog from the ground.

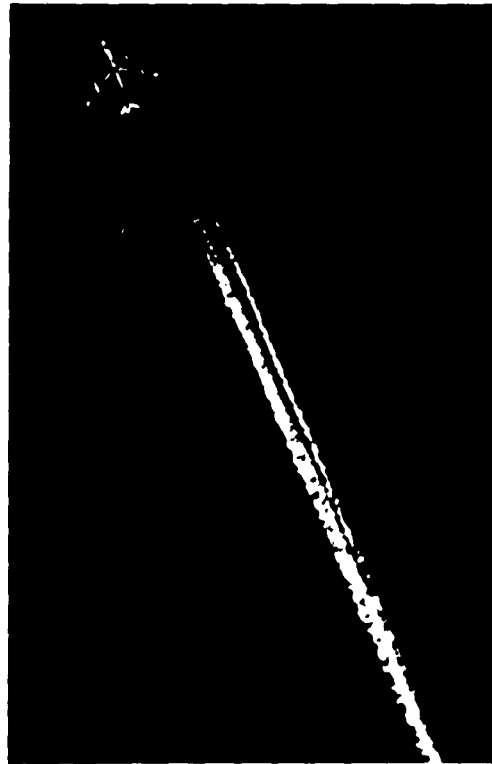


The equipment carried aloft in aircraft under the Cloud Buster Project forms dry ice pellets in the rotating drum shown in the center of the photograph.

**CONTRAIL SUPPRESSION:** There was a somewhat related dissipation effort that was brought to a successful conclusion during 1961, involving one of the most obstinate of Air Force operational problems, that of contrails. Condensation trails usually form at altitudes above 25,000 feet. The AFCRL technique for chemical suppression of these contrails was aimed at preventing the growth of the water vapor particles beyond a certain maximum size, when they would not scatter visible light. The equipment, as it was developed for a large bomber aircraft, weighed about 400 pounds when empty. When the system was in operation, the weight of the chemical used for contrail

suppression, which was added directly to the exhaust of the jet engines, was about two percent of the weight of the fuel consumed.

In April 1961 a Strategic Air Command B-52 bomber was modified to suppress contrails on all engines and the equipment was successfully test flown. Later, a B-47 test aircraft was used for further experiments aimed at improving system components. In the fall of 1961 a ground-handling and storage system for the contrail suppression agent was constructed at Kirtland AFB, New Mexico, to help develop proper ground-servicing pro-



The effectiveness of AFCRL's contrail suppression is dramatically illustrated in this photograph. The suppression apparatus is employed only on the left engines. The right engines generate normal contrails.

cedures and equipment to support aircraft which may use the system.

#### CLOUD PHYSICS RESEARCH

A program of refractive index measurements at Cape Canaveral in support of Project Mercury orbital and Ranger lunar launchings, and studies of severe storms, highlighted an extensive AFCRL effort during 1961-1962 to accumulate new data on clouds and their properties. The severe storm studies were conducted in cooperation with the U. S. Weather Bureau, while the refractive index measurements were made at the behest of the Air Force Systems Command.

In April-May 1961, during their joint studies of storms over the Great Plains region, laboratory personnel utilized a U-2 aircraft to fly some 10 weather missions to obtain useful cloud photographs. At the same time, a C-130 aircraft gathered airborne data on cloud and atmospheric structures in and around various squall lines. One C-130 flight across a 500-mile long dry line brought in detailed information on cloud and clear air temperatures and the refractive index structure. Later analysis of measurements made near several Oklahoma squall-line thunderstorms revealed that the pronounced electric fields in the clear air generally reached a maximum near the regions of more active precipitation within the storm clouds.

The "dew point front," a particular phenomena of the synoptic weather map, also was investigated in detail, with three such fronts being photographed and penetrated repeatedly at various altitudes. AFCRL meteorologists discovered that the gradients of humidity associated with these fronts were extremely large (larger than could be resolved with the 0.01 second response time of the aircraft instru-

ments). It appeared that radar echoes received from these fronts were caused by the gradients of humidity since the associated clouds were of insufficient size to produce radar echo through scattering. The 1961 observations further revealed that there were specific characteristics of cumulus clouds and other pattern structures along the fronts, which should be clearly identifiable at satellite height.

In follow-up field studies conducted during April-May 1962, AFCRL personnel aboard the C-130 directed an instrumented F-100F and T-33 into thunderstorms containing both radar echoes and high electric field charge centers. Through analysis of data collected, the scientists hoped they could obtain a new insight into the dynamics and structure of storm clouds. The U-2 also participated in the 1962 severe storm investigations, and carried several new devices to collect data including: an electric field meter, a radiometer, an atmospheric ozone meter, and special filters for sampling particulate matter in the stratosphere.

In related AFCRL cloud physics studies out of Flagstaff, Arizona (Project High Cue), airborne measurements were made aboard the C-130 during 13 flights in the summer of 1961. The U-2 aircraft also gave photographic support, while from the ground simultaneous radar, stereophotographic and special mesoscale weather observations were made. These studies were aimed at measuring changes in the liquid water content of clouds and their internal temperature, while continuously observing their growth.

Another Flagstaff study was concerned with determining the mass outflow of cumulus congestus and thunderstorms, based on photogrammetric measurements of the spreading of the clouds and their thunderstorm

anvils. AFCRL scientists found that the thunderstorm anvil represented a considerable outflow of cloud matter, due to the internal cloud circulation, and was not merely decaying cloud material being blown by prevailing winds. In connection with this study, AFCRL established an IBM 650 computer program to make possible more accurate reduction of the raw photogrammetric measurements as well as to increase the rate of cloud analysis.

In September 1961, again bringing the U-2 into play for high altitude observations, AFCRL meteorologists also made several flights to photograph Hurricanes Carla and Esther while simultaneous photos were being taken by the Tiros III weather satellite. This operation marked the first time that such flights were made in conjunction with satellite passes over hurricane storm systems.

#### **REFRACTIVE INDEX MEASUREMENTS:**

In November 1961, at the request of the Space Systems Division, AFSC, the Laboratories initiated a program of refractive index measurements over Cape Canaveral in support of the Mercury and Ranger programs. A series of some 70 test flights were made during November and in January 1962, using the C-130 aircraft. Information was collected on the sharpness and irregularity of the top of the moist layer, as well as on effects of thermals and clouds in producing refractive index anomalies in the lower atmosphere.

Subsequent analysis of an estimated 160 hours of cloud physics data collected on the flights pointed up the fact that in any given situation, the prediction of the extent of the horizontal nonhomogeneity of the refractive index was dependent on complex factors — including wind shear, moisture structure, cloud type and cloud size and

number. In this connection, two comprehensive in-house reports were issued during the period, the first describing the climatology of the cloud effect on radio refractive index values and providing maps of the U. S. showing differences between the refractive index in clouds and the surrounding air. The second report considered the natural spacing and distribution of clouds, to aid computation of cloud interception by two ground-based parallel lines of sight.

The AFCRL cloud physics studies described above were immeasurably advanced during the period by significant improvements achieved in airborne instrumentation. Most important of these was a precise drift-free digital metering and recording system for the microwave refractometer. Airborne vortex and refractometer temperature sensing systems also were improved through use of very stable solid-



This photograph shows the typical cloudiness usually existing on the moist side of the dry line versus the absolutely cloud free area which exists on the dry side of the line.

state amplifiers, temperature-controlled bridge circuits, and automatic ranging. In addition, a three-dimensional atmospheric electric field measuring system was developed and installed in the C-130. Other unique instrumentation included a set of four electric field and recording systems for ground use. These were emplaced at selected ground sites in Oklahoma in conjunction with the 1961-1962 severe storm studies in that area.

#### **ATMOSPHERIC CIRCULATIONS**

The circulation of the first mile or so of atmosphere, as well as upper level circulations, have directly affected Air Force missile and aircraft operations. During the period both circulations were intensively studied by AFCRL scientists, with one special research effort centered on accumulating detailed wind diffusion data at Cape Canaveral and Vandenberg Air Force Base missile sites.

**TOXIC FUELS AND THE WIND SYSTEMS:** The requirement for detailed wind diffusion information arose in connection with Air Force plans to use toxic fuels in various missile systems. After becoming aware of a potential downwind safety problem in the event of a missile accident, early in 1961 the Ballistic Systems Division requested the Laboratories to undertake a special research program on the local climatologies. This effort was subsequently launched by AFCRL personnel on both the East and West Coast. It involved release and down-wind sampling of tracer elements in the free atmosphere, plus simultaneous measurements of the pertinent meteorological factors.

The tracer release or diffusion experiments, conducted with contractual support, utilized 530 tracer sampler positions arrayed on concentric arcs

which extended downwind from the release points at distances up to three miles. At each position a membrane filter, aspirated by a gasoline engine-driven vacuum pump, was exposed to the tracer cloud during and immediately following the tracer release period. The filters were then collected and assayed by an automatic counting device. During 1961 and 1962 some 160 tests were conducted, and the experimental results were used in development of diffusion prediction equations appropriate for Cape Canaveral and Vandenberg Air Force Base.

An automatic micrometeorological observing and data processing system also was designed for measuring micrometeorological parameters at a number of sites at each range. The entire system, appropriately designated the Weather Information Network and Display (WIND), provides continual monitoring of the diffusion conditions and, for the first time in the history of meteorological instrumentation, gives visual presentation of real-time circulation patterns over tens of square miles. At the close of June 1962 WIND systems were in operation at both missile ranges.

**THE LOW LEVEL JET:** In related studies, during the period AFCRL meteorologists utilized a 1428-foot television tower at Cedar Hills, Texas, instrumented at 12 levels from 30 feet to 1420 feet, to measure wind and temperature variations in the low-level jet phenomena. A detailed picture was obtained of wind and temperature structure during formation and decay of the jet, as well as the relationship between the jet and the nocturnal inversion. Thus, for example, during the first four months of 1961 a number of jets was detected, all with their maximum winds below 1,200 feet. One



During the reporting period, AFCRL established special meteorological systems at Vandenberg AFB and at Cape Canaveral, used to predict the extent to which winds and other atmospheric factors would result in the dissipation of missile gases.

of the strongest ones was recorded during the night of 22-23 February 1961. At 5 p.m. the wind at 900 feet was about 28 miles per hour; by 3 a.m. it had increased to 67 miles per hour. At that time the wind speed 30 feet above the ground was only 15 miles per hour; the difference of 52 miles per hour in 870 feet was one of the largest on record.

At the upper end of the scale, in-house efforts were oriented toward atmospheric circulations in regions where data remained scarce and incomplete—above 100,000 feet. Preliminary



A 1400-foot TV tower near Dallas, Texas with instruments at various levels for measuring gradations in wind velocity as a function of altitude was used by AFCRL for several meteorological experiments, including the study of the low level jet.

information collected by meteorological rockets showed there was no radical variation of the synoptic features in the layer between 100,000 and 160,000 feet, although individual features of the circulation appeared to weaken or intensify with height and to become geographically displaced. Theoretical investigations of the dynamics of the atmosphere between 280,000 and 320,000 feet were begun, utilizing observations of noctilucent clouds and meteor trails. Other upper atmospheric circulation studies centered on the effects of solar energy radiations. On the basis

of data collected, it appeared that a small but significant relationship existed between solar corpuscular radiation, as measured by variations of the earth's geomagnetic field gradient, and the subsequent behavior of the troposphere pressure field.

AFCRL studies of the upper atmosphere also involved consideration of the presence of ozone, the faintly blue, gaseous allotropic form of oxygen, a principal absorber of solar ultraviolet radiation. Since ozone is considered basic to an understanding of the thermal structure at higher elevations and has important applications as a tracer of atmospheric motion, AFCRL actively pursued a program to measure its distribution. During 1961 a series of field tests were conducted to demonstrate a new balloon-borne dry chemical ozonesonde, developed under contract. The results indicated that the instrument was capable of providing accurate and high resolution measurements of ozone that was required for a multiplicity of research purposes. An intensive program to measure the vertical distribution of ozone was scheduled to start in January 1963 at an experimental network of 10 stations extending from the Canal Zone to northern Canada.

#### **SATELLITE METEOROLOGY**

The excellent photos obtained from the five TIROS weather satellites launched since April 1960 for the National Aeronautics and Space Administration,\* clearly demonstrated that meteorology has at its disposal a tool capable of providing cloud analysis on as small or large a scale as desired. The satellite view has already revolutionized the

\* Launched on 1 April and 23 November 1960; 12 July 1961; and 8 February and 19 June 1962.

meteorologist's capability to study the dynamics of the atmosphere and to improve forecasts.

#### **TIROS PHOTOS AND COMPUTER**

**ANALYSIS:** The Cambridge Research Laboratories, which established a satellite meteorological research group in February 1958, have vigorously pursued studies of a special problem associated with the new tool—that of photo interpretation and data analysis. Toward this end, photographic “keys” were developed during the period which equate cloud types to such photo parameters as structure of cloud patterns seen, geometrical configuration of patterns, dimensions between and within pattern elements, and the relative brightness of cloud elements. The latter was basic not only to subjective photo interpretation, but also for automated machine analysis and interpretation since the primary input to the computed system was brightness in terms of digital voltages of the scanned spots.

The use of computers by AFCRL was dictated by the large volumes of data being recorded by the satellites. During the early TIROS flights, a relatively slow process was used, involving locating, rectifying and extracting data in real time with the operational output dependent on the subjective interpretation of meteorologists. The procedure also was not adjustable to efficient transmission through normal communication channels or compatible with the digital form of communications required by organizations with computer-oriented modes of operation.

To resolve these problems, an AFCRL contractor devised a machine program for the production of rectification grids. This system saves several hours over the previous method of fitting grids to the pictures, and it was later adopted by the U. S. Weather Bureau in its IOU

(immediate operational use) program. By way of preparing for the completely automatic reduction, and possibly even analysis of satellite data, two additional contractual efforts were supported by AFCRL. In one the feasibility of rectifying individual photographs, superimposing map coordinates on them, and joining an entire sequence of pictures into a mosaic, was shown practical by digital computer techniques. The other study, still in its early stages in June 1962, centered on research into the feasibility of automatically extracting information of use to the meteorologist by machine methods directly from the satellite output.

While advances in data processing were being made, another AFCRL contractor studied satellite photos and concluded it was possible to determine the stage of development in the life cycle of mid-latitude cyclones. In



Tiros satellite photograph with a computer generated grid superimposed is shown here. This photograph shows lower California and the Gulf of California and was taken 21 August 1961.

follow-up studies by AFCRL meteorologists, a family or wave train of cyclonic systems was tracked and studied as it moved from Japan to the central United States over a seven-day period. The stage and intensity of mature cyclones also were investigated by observing satellite pictures of three storms over the central part of the country. At the end of June 1962 the Laboratories were continuing their research on the problems of photo interpretation and data analysis.

#### WEATHER RADAR RESEARCH

Another continuing AFCRL program involved the use of radar techniques to study the spatial distribution, intensity, variability and development of clouds, precipitation, refractive index inhomogeneities and ionized regions. During 1961-1962 the most important activity in this area centered on initiation of a program using Doppler techniques to improve the potential of radar for cloud and precipitation studies.

Work on Doppler signal processing, both theoretical and experimental, was carried out, based mainly on statistical analysis of narrow band Gaussian signals and various experiments on simulated signals. One application of the Doppler technique was in the measurement of air motion, considering precipitation or chaff particles as tracers. The method provided a very useful means for studying the variability of the wind on a fine time scale. Complete wind soundings could be made in about four minutes with existing instrumentation, with accuracies exceeding those of conventional balloon tracking techniques.

**THUNDERSTORM WARNINGS:** One of the major goals of these radar studies was to devise warning procedures for severe thunderstorms, using all suitable

observational data. In this connection, radar analysis of a tornado-producing thunderstorm tracked near Geary, Oklahoma in May 1961, showed an echo configuration remarkably similar to a severe hailstorm previously studied and reported on in England. In both cases there was an overhang, or region of intense precipitation on the right flank of the storm, lying above areas near the ground that contained little or no precipitation. When the storm was most severe, the overhang terminated toward the rear of the turbulence in a nearly vertical wall of very heavy precipitation, while nearby there was a narrow wedge-shaped chimney signifi-



AFCRL pioneered in weather radar techniques which are used widely today. A cyclonic system is seen on a radar scope.



ing the location of the most intense updraft.

Related experiments utilizing radar also were conducted at Flagstaff, Arizona, as part of efforts in the summer of 1961 to detect the electromagnetic radiation associated with many severe storms and tornadoes. The reflectivity structure of growing cumulus was measured at two radar wavelengths, 0.9 and 1.8 centimeters and sferics data were recorded in young and growing thunderstorms.

Other radar research pursued during the period was directed towards developing new instrumentation for measuring, processing and displaying



The mountains near the Flagstaff Field Site are breeding grounds for clouds, and thus the Flagstaff site is an excellent location for the study of cloud dynamics.



Two T-11 cameras of the type shown here were used at the Flagstaff Field Site in Arizona to take stereogrametric cloud photographs. Such photographs provide information on the size and growth rate of convective cells.

atmospheric signals. This effort included a preliminary evaluation of the Weather Radar Data Processor, which digitizes video and position information obtained from the CPS-9 Weather Radar; also the installation and preliminary evaluation of the linear/circular polarization kit on the CPS-9; and multiwavelength radar reflectivity studies at 3.2, 0.9 and 1.8 centimeters, conducted at Flagstaff and at Blue Hill, Massachusetts.

#### HIGH LEVEL CLIMATOLOGY

In seeking to provide a more correct description of the atmosphere at higher

altitudes, to meet the growing requirements of aerospace technology, during the period AFCRL contributed to several notable advances in climatology. One contribution, by the Meteorological Development Laboratory, involved the preparation of a new Standard Atmosphere based on a complete analysis of all available radiosonde, rocket and other observations of temperature, density and pressure at the higher elevations.

#### **A REVISED STANDARD ATMOSPHERE:**

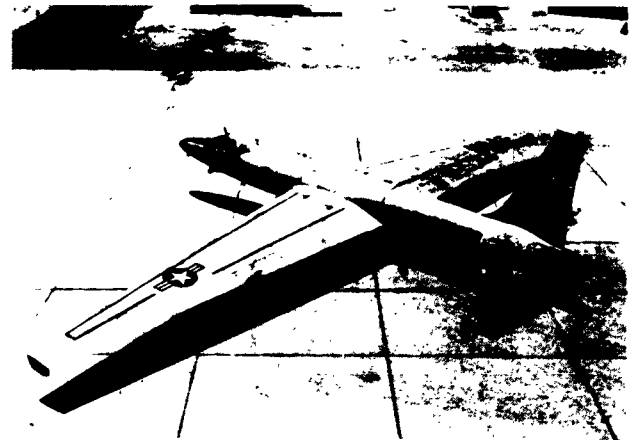
The AFCRL revised Standard Atmosphere, which superseded 1956 and 1959 models, was almost identical with the old ones up to 20 geometric kilometers. But at higher levels it was further refined. For example, at 50 kilometers its temperature was given as  $-2.5^{\circ}\text{C}$  rather than the  $95^{\circ}\text{C}$  in the older versions. At 90 kilometers (295,000 feet) its temperature was given as  $-92.5^{\circ}\text{C}$ , which fell between the values of the 1956 version ( $-76.5^{\circ}\text{C}$ ) and the 1959 model ( $-107.5^{\circ}\text{C}$ ).

In September 1961 the AFCRL revisions were presented to, and approved by, the U. S. Committee on Extension to the Standard Atmosphere. Official publication was set for the fall of 1962 together with revisions for altitudes from 90 to 700 kilometers. This revised U. S. Standard Atmosphere also was submitted to the International Civil Aviation Organization for international approval for altitudes of interest of aviation. Besides work on the Standard Atmosphere, AFCRL meteorologists—seeking to provide more detailed atmospheric description for specific altitudes—also developed Supplemental Atmospheres at  $15^{\circ}$ ,  $30^{\circ}$  and  $45^{\circ}\text{N}$ . Others were in preparation for  $60^{\circ}$  and  $75^{\circ}\text{N}$ . For each latitude summer and winter versions were provided, except that the Tropical Atmosphere ( $15^{\circ}\text{N}$ ) was for

the year as a whole. Moisture content of the air was specified in the Supplemental Atmospheres, but not in the Standard.

**WIND AND DENSITY STUDIES:** The study of the variability of winds over short time intervals was another phase of the AFCRL research program to increase understanding of atmospheric processes. The low-level jet phenomena discussed earlier was one aspect of this research. Another, conducted during the summer of 1961, involved hourly rawinsonde flights at Hanscom Field, whose preliminary results on variability from flight to flight were reported to the National Symposium on Winds for Aerospace Vehicle Design. Vertical extension of the analysis to between 15 and 45 miles above the Earth, based on data obtained from 23 hourly Arcas-Robin rocket soundings, indicated a marked diurnal cycle of wind variability at those elevations.

The AFCRL wind and density studies, as the above Symposium indicates, were directed toward obtaining data that



A U-2 aircraft is made available to AFCRL for meteorological experiments where it is necessary to conduct the experiment well above major weather patterns.

could be used in planning the flights of aerospace vehicles such as the Air Force Dyna-Soar. During 1961 both contractor and Air Force in-house agencies involved in the Dyna-Soar development program, sought the Laboratories assistance in obtaining detailed information on winds, temperatures and atmospheric density. Several AFCRL studies were initiated and reports written that provided arrays of means and standard deviations of density at two kilometer intervals, at altitudes up to 32 kilometers, and coefficients of correlations between levels for six different climatic regions.

In the search for more and more detailed atmospheric density information at the higher regions above 100 kilometers the Photochemistry Laboratory also conducted a number of experiments using rocket probes and satellite measurements which produced useful data. One experiment involved a flight in March 1962 of a Nike-Cajun carrying a 7-inch falling sphere which contained an improved transit-time accelerometer. The drag experienced by the sphere was measured by the accelerometer and good density data was obtained to an altitude slightly greater than 100 kilometers. Two expandable sphere experiments, flown on a Nike-Cajun and an Aerobee rocket, also brought in density data at altitudes of 107 and 100-140 kilometers respectively.

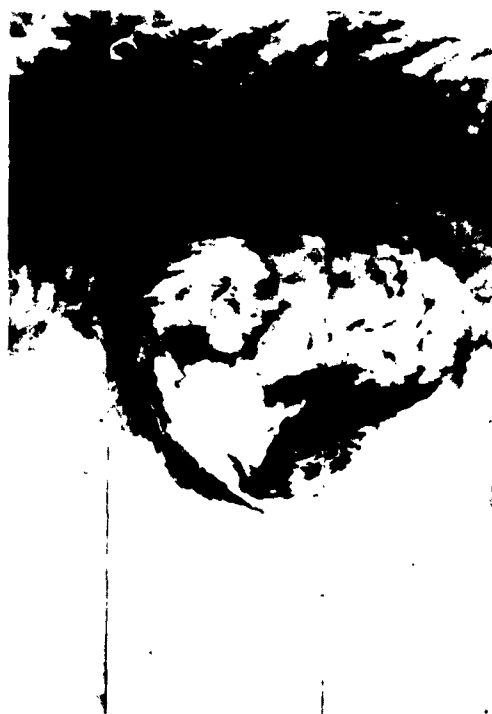
To obtain density information at satellite heights, the Photochemistry Laboratory made use of a very sensitive cold-cathode ionization gauge, flown aboard Discoverer 25 into polar orbit (17 June 1961) and recovered from the sea the following day. The flight provided the scientists significant density data at an altitude of 400 kilometers.

The density of the upper atmosphere also was calculated by observing the

slowing down of satellites as they orbit the Earth — based on the amount of drag the satellites experienced at perigee (above 200 kilometers). In a related study, it was discovered that solar flare phenomena directly affected atmospheric density. Thus, for example, within a day following two large solar flares in November 1960, it was found that the density of the atmosphere at 205 kilometers had increased by a factor of about two in one case, and a factor of 1.5 in the other. The effect was attributed to the corpuscular radiations emitted by the sun.\*

During the period AFCRL scientists

\* See discussion of solar flares in Chapter VII.



Hurricane Carla which formed in the Atlantic in 1961, was photographed by an AFCRL-equipped U-2 aircraft flying above 50,000 feet. Simultaneously, the hurricane was photographed by the Tiros satellite for comparison purposes.

—continuing related climatological research—gave considerable attention to studies of the effect of upper level winds on air intercept and bombing operations. Errors in wind forecasts supporting SAGE-guided fighter plane intercept missions were fully analyzed, based on wind errors introduced into an IBM 704 computer simulating operational conditions. Results of the study indicated that the existing state of the art in wind forecasting was generally adequate, although AFCRL meteorologists noted there were certain geographical, seasonal and operational limitations.

The problem of predicting winds aloft in support of manned bomber operations was also approached from a statistical point of view. Prediction equations were developed for a number of techniques and then tested on independent data. Related research was continued in an effort to develop better methods for estimating the probability of future weather events. Tests of "least squares" indicated that reliable probability estimates could be obtained when the predictors were defined both as continuous variables, or expressed in discrete, mutually exclusive categories.

#### **EQUIPMENT RESEARCH**

As has been indicated, one of the major deficiencies of modern meteorology has been the lack of data on the higher layer between 70,000 and 250,000 feet. It was in the attempt to resolve this problem that AFCRL concluded several successful equipment development programs during the period which served to advance meteorological research.

**THE ARCAS-ROBIN SYSTEM:** One of the important programs centered on the Arcas-Robin meteorological sounding technique (described below), which successfully passed its feasibility tests

during the summer of 1961. These tests consisted of 200 rocket launchings, 100 at Eglin AFB, Florida, 60 at Holloman AFB, New Mexico, and 40 at Wallops Island, Virginia. Balloon radar acquisition was accomplished during 90 percent of the flights. The system was subsequently classified as "tentative standard," although development continued, so that procurement could be initiated in support of weather operations that required new meteorological data at the higher levels. Operational use of the Arcas-Robin system began in March 1962.

The Arcas is a small solid-fuel low acceleration rocket, 80 inches long, 4.5 inches in diameter and weighing about 75 pounds. It has a thrust of about 330 pounds. The Robin is a one-meter diameter  $\frac{1}{2}$ -mil mylar sphere containing a built-in aluminized  $\frac{1}{4}$ -mil mylar corner reflector. After ejection from the rocket at a height of about 250,000 feet, the



The Arcas Robin rocketsonde system is loaded into its launcher at the Air Proving Ground Center's rocket launch site on Santa Rosa Island, near Fort Walton Beach, Florida.

Robin inflates to a super-pressure of 10-12 millibars through vaporization of 35cc of isopentane carried in a small capsule inside. Ground based radar is used to track the falling sphere down to 100,000 feet where it starts to deflate.

During the above sequence the space positions of the sphere can be reduced to determine such meteorological parameters as wind, density, temperature and pressure. The whole system, which was designed for operational weather station use, requires only two airmen to handle the rocket and launching equipment. During the development program, several environmental chamber tests of the Robin were conducted at Wright-Patterson AFB, Ohio, to evaluate the ejection mechanism as well as vari-



The Robin sphere consists of a mylar balloon with aluminized mylar corner reflector for radar tracking.

ous sphere films and inflation devices. Wind tunnel tests of spheres at the University of Minnesota resulted in establishing the drag coefficient values incorporated in the data reduction computer program.

The feasibility of ejecting the Robin from a Loki-type sounding rocket also was successfully tested during 1961 at the White Sands Missile Range. The Loki vehicle is capable of reaching heights of 200,000 feet and has the advantage of being considerably lower in cost than Arcas. A comprehensive Loki-Robin test program was scheduled to begin during the summer of 1962.

**THE ROSE SYSTEM:** Another important AFCRL technique developed during 1961 was designed to provide detailed wind shear information in the lower atmospheric levels from the surface to 75,000 feet. Designated the Rose system, this technique involved use of a hydrogen-filled rising rigid sphere tracked by the AN/FPS-16 radar. An aluminized two-meter diameter half-mil mylar sphere, Rose was super-pressured throughout the flight to about eight millibars. A finite difference data reduction method provides wind information to an accuracy of better than one meter per second over a height interval of 100 feet through the strongest of wind shears. Relatively inexpensive, the Rose technique was adopted by the National Aeronautics and Space Administration as well as by the Air Force to support range operations. Although further refinement of the sphere was underway, the technique was expected to be standardized by late 1962.

The new radiosonde neoprene balloons also were field tested at tropical, arctic and temperate zone locations from May through November 1961. They were a M1-537 100,000 foot day-

night balloon, and a M1-564 120,000 foot day-night balloon. Several other AFCRL programs were initiated to develop a 100,000 foot fast-rise balloon as well as a 150,000 foot balloon.

An integral part of the above efforts to obtain more knowledge of the higher levels involved the development of improved atmospheric sensing instruments. Among them was a dew point hygrometer, which operates on the principle of detection of the presence of alpha radiation from a polonium source. This device employs a Peltier cooler and an optical mirror system and was successfully tested in December 1961, demonstrating an ability to measure frost points as low as  $-60^{\circ}\text{C}$ . Another sensor, a low cost polyelectrolytic humidity device, also was designed during 1961. It uses a polymer plastic having electro-conductive properties that vary with the amount of moisture absorbed by the material. Test flights of the latter device were scheduled for the summer of 1962. Development of a microwave refractometer, a device urgently needed at the missile ranges, also was initiated by AFCRL. The refractometer employs the principle of sampling the air between the plates of a specially-designed capacitor; the capacitance varying as a function of the atmospheric dielectric constant, provides an indication of the index of refraction.

**A LIGHTNING DETECTION SYSTEM:** During the early months of 1962, a lightning detection system designed by the Laboratories also was tested at Patrick AFB, Florida. Its purpose is to help missile safety officers to predict potentially-dangerous atmospheric electrical charges. The equipment contains a lightning stroke detector which responds to sudden changes in the

electrical field, and a corona current detector which measures the near-vicinity electric field intensity. At its most sensitive level, however, the system can detect a lightning discharge at a maximum range out to 100 kilometers. Successful development of the system was expected to be particularly useful to ICBM crews in areas of high thunderstorm activity.

One of the highlights of AFCRL equipment research during the period involved the successful demonstration at Westover Air Force Base of the Weather Observing and Forecasting System (433L). Many of the original ideas and the background research for the system equipment originated in the Laboratories in the late 1950s.

**AUTOMATIC METEOROLOGICAL STATION:** The major accomplishment was the completion of the Automatic Meteorological Station AN/FMQ-5. This station accepts inputs from airfield sensors (wind, transmissivity, cloud height, etc.), converts analogue signals to digital values, performs computations and stores meteorological message elements for various transmission schedules. The automated inputs, plus several non-automated observations, are then transmitted at various speeds over local and long-distance communication circuits.

During 1961 three such stations were delivered by the contractor, with AFCRL personnel supervising the acceptance and Category I testing of the first unit. The station was moved to Westover AFB where it was installed in an Air Weather Service facility and, in December 1961, was successfully demonstrated for high ranking Air Force officials. The second unit was installed in the System 433L test building at Hanscom Field; while the third

unit was stored pending possible installation at the Federal Aviation Agency's test facility at Atlantic City.

In the meantime AFCRL research efforts were continuing on advanced versions of the equipment, so as to reflect changes in Air Weather Service operational concepts. The goal was to have the final operational configuration ready to begin quantity procurement by the end of calendar year 1963. Among new advances made by AFCRL meteorologists in the system were: a force-balance digital barometer which makes possible automatic accurate station pressure measurements, and resolution of the problem of precise analogue to digital cloud height signal conversion. A new cloud height measuring set for tactical use was developed, the AN/TMQ-14, a highly mobile unit using a Xenon arc light source. Many of the set's features were applicable to the standard fixed station equipment.

In other "far out" equipment research, AFCRL personnel initiated studies of the new laser device, and of acoustical techniques (in coordination with electromagnetic probing) as possible methods for the indirect probing of the temperature, humidity and clear air turbulence in the atmosphere.



One of the strongest in-house solid state research programs in the Federal government is conducted at AFCRL's Electronic Material Sciences Laboratory which has made basic contributions to silicon technology, single crystal technology, material purification, radiation effects investigations, and device fabrication. The Laboratory pioneered in new techniques for the ultrapurification of silicon, and in silicon carbide research. These and other important advances contributed to the manufacture of superior semiconductor devices, diodes and transistors, and infrared and computing elements that today play essential roles in space age military applications.

During the 1961-1962 period, while the build-up of the organization's solid state research capability was continuing,\* AFCRL scientists pursued their investigations of the basic mechanisms and technological problems associated with materials. The growth of single crystals of controlled purity and structure such as doped aluminum oxides for maser and laser application, was the largest single endeavor. Research into the effect of radiation on electronic materials and devices was expanded, and ultrapurification of materials and investigations of new semiconductor device concepts were continued. The semiconductor work centered on germanium, silicon, boron, silicon carbide, bismuth telluride, and compounds such

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\* Highlighted by completion of AFCRL's irradiation facility in September 1961, and a new Crystal Physics Laboratory occupied in February 1962. In addition, in the spring of 1962 construction was started on a new Radiation Physics Laboratory.



as magnesium stannide. AFCRL personnel continued studies of the properties of diamond — a potentially useful high-temperature semi-conductor material. Using improved techniques, they were able to grow larger and more perfect diamonds in the AFCRL tetrahedral anvil press.\* Research also was pursued on optical materials, including aluminum oxide and calcium fluoride as host lattices with dopants (impurities) that exhibit energy levels appropriate for light amplification action; and on rare-earth garnet structures and the complex cyanides.

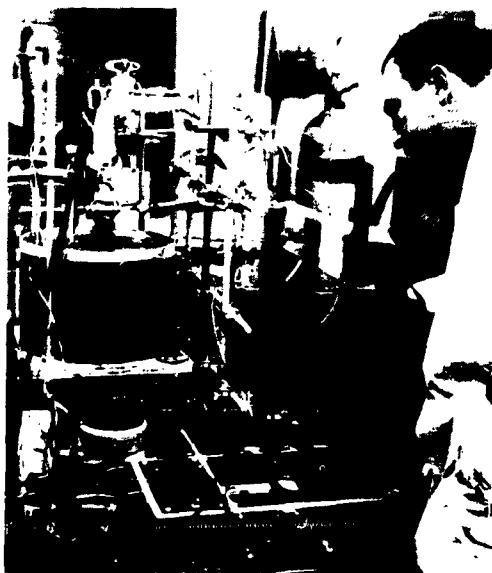
A great variety of crystal growing techniques and furnaces, some of them unique, were employed by the laboratory. Equally important, a variety of techniques were used for analyzing the crystal, the most valuable of these being x-ray diffraction. In general, during the period the laboratory's solid state research program was narrowed to permit more intensive efforts in fewer significant areas rather than broader coverage of the material science area.

#### ULTRAPURIFICATION PROCESSES

The presence of a few atoms or molecules in a material that are different from the atoms or molecules in the "pure" system can greatly modify the electrical properties of the material. Quantities as small as  $10^{12}$  atoms per cubic centimeter of matrix can affect these changes. Of the many large gaps in understanding the growth and performance of single crystal materials, the greatest centers on the effects of chemical and structural imperfection.

For semiconductors, the role of impurities is fairly well understood. In magnetic materials, however, the role of

\* AFCRL created its first artificial diamonds in January 1960, thirteen months after the initiation of its ultra high pressure research program.



Ultrapurification of materials requires that the materials be processed through several stages. One aspect of the ultrapurification process is shown here.

impurities or dopants is another matter. For example, two ruby crystals grown under presumably the same conditions often have quite different electronic characteristics. The objective of much of the laboratory's research in electronic materials is to grow crystals with clearly predictable and consistent properties. A second objective is to grow crystals with "tailor-made" characteristics.

The problem of "tailor-making" materials, however, was complicated by the fact that the host material, as a first step, must be devoid of major contaminants — thus enabling scientists to add controlled amounts of dopants and "impurities." A major effort of AFCRL, therefore, has been directed toward producing ultra-pure materials.

#### ULTRAPURIFICATION OF SILICON:

Scientists in the materials laboratory initially devoted themselves to the ultrapurification of silicon for semiconductor

research. In-house studies of the problem led to the adoption of the preparation of the intermediary, silicon tetraiodide, and purifying this material by elaborate methods. Five purification steps were used, essentially involving the use of a then new technique of void zone purification. The purified silicon tetraiodide was then decomposed into highly purified silicon.

When the whole process was reported to the International Conference on Solid State Physics in Electronics and Telecommunications, in Brussels in 1958, widespread scientific interest was generated. Today the AFCRL basic process is commercially used in several countries. During 1961 a U.S. patent was granted for the AFCRL apparatus developed for the preparation of ultra-pure silicon, and a patent application for the process itself is still pending.

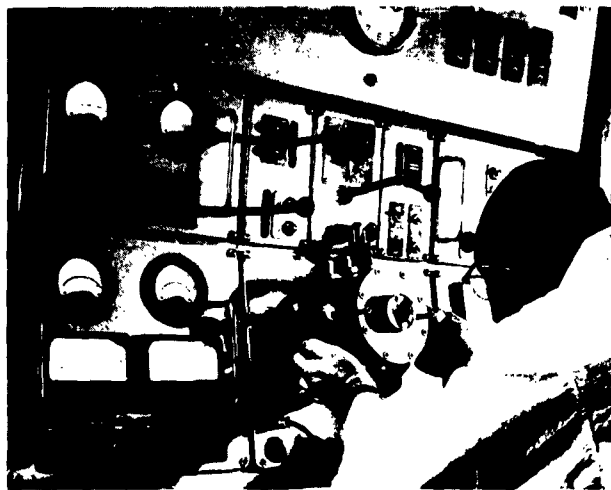
The above advance in techniques for preparing high-purity silicon was but the beginning of the organization's research into the ultrapurification of semiconductor materials. When a need arose for preparation of high-purity magnesium and tin, elements required for synthesizing magnesium stannide, those materials were successfully prepared free of metallic impurities at the ten parts per million level. When AFCRL initiated its laser studies in January 1961\*, a requirement arose for preparation of high-purity chromium for use as a dopant in alumina. An electrolytic approach was adopted and a useful chromium product obtained. At the same time high-purity alumina was produced through a recrystallization process. Other successful experiments produced high-purity materials of such widely dissimilar materials as silicon carbide, lead and naphthalene.

\* For a report on AFCRL laser research, see Chapter V.

In seeking out new techniques to attain high levels of purity, another method that suggested itself was the use of vapor-phase chromatography to purify chemical intermediates. This technique was used originally as an analytical tool by the petroleum and organic chemical industry. An apparatus was designed and placed in operation by AFCRL, and successful separation of the homologues of the methylchlorosilanes was accomplished during the period. Continuing studies have centered on the separation of the halides of boron, silicon and arsenic.

**DETECTION OF IMPURITIES:** While making advances in the area of ultrapurification, AFCRL scientists also devoted a great deal of time and effort to increasing the sensitivity of their analytical tools for detecting impurities. One of their important achievements in this area was the perfection of neutron activation analysis, a method which proved superior to existing techniques (i.e., emission spectroscopy) for detecting certain impurities. The neutron activation technique involved irradiation of a sample in a nuclear reactor and the subsequent identification of the radioisotopes of the impurities, thus produced by a complex radiochemical quantitative analysis allowing an identification of the impurities' individual specific radiation characteristics. For many elements of the periodic table, this became work of a routine nature.

By 1961 the special "know-how" and reputation achieved by AFCRL scientists in detection of impurities brought dozens of requests from private industry and contractors for analytical work on materials. During calendar year 1961, for example, some 325 samples of materials were analyzed for their impurities by laboratory personnel, using not only neutron activation analysis but also emission spectroscopy, gravimetric and



AFCRL's mass spectrograph is used here for the analysis of boron in tungsten. Boron is one of the most difficult materials to eliminate in the purification of materials.

volumetric methods. These samples included alums, boron and bismuth compounds, silicon and silicon compounds, chromium, nickel, yttrium oxide, etc.\*

For several elements of the periodic table, more rapid and inexpensive methods and better sensitivities beyond the techniques above were required. To meet this additional need, an AFCRL contract was let in September 1961 to procure a solid-source mass spectrograph capable of determining one part per billion of boron impurity in silicon. When this instrument becomes operational in mid-1962, AFCRL will be one of the few research organizations in the world capable of offering ultra-trace analysis by three of the most sensitive methods available: neutron activation analysis, emission spectroscopy, and solid-source mass spectrography.

\* The service was performed for private industry in those cases where it was deemed the Air Force and defense establishment would be ultimate beneficiaries.

In this connection, the Laboratory also supported various contractor research activities to further develop trace and other sensitive analyses including: (a) Stoichiometric analysis by differential spectrophotometry; (b) better understanding of the emission process and fuller utilization of the emitted radiation in emission spectroscopy; (c) development of techniques for solid-source mass spectrography; (d) scope increase of activation analysis by use of short-lived (under two hours) activities; and (e) development of an activation analysis scheme utilizing ion-exchange and multichannel gamma spectrometry.

During the period, several new important areas of ultrapurification research were begun. One involved the preparation of ultrapure boron using the triiodide as an intermediate. Another investigation centered on the decomposition of organic compounds in an attempt to degrade them to semiconductors. It has been known that the complete degradation of an organic insulator results in a conductor. This research was aimed at defining the conditions under which a semiconductor might be formed using thermal, particulate and non-particulate radiation sources.

As interest expanded in high purity rare-earth elements for use as dopants in lasers and masers, contractual work was supported to develop methods for purification of four of those elements to impurity levels of the part per million. The in-house preparation of high purity gallium was experimentally studied via the synthesis and subsequent decomposition of lithium gallium hydride. This intermediate was obtained from the reaction of gallium trichloride with lithium hydride. At the close of the period studies were continuing into various methods of ultrapurification such as vapor-phase chromatography,



Vapor phase chromatography is seeing increasing use as a technique for analyzing constituents of materials.

void-zone purification, electrophoresis, ion exchange techniques, electrolysis, electro-osmosis and dialysis. Work in the preparation of thin films focused on the decomposition of  $\text{BI}_3$  to boron using hydrogen as the reductant. Successful films have been produced on silicon substrates and the physical and electromagnetic properties are being investigated.

#### CRYSTAL PHYSICS

Besides its ultrapurification investigations, the study of crystal physics as it applied to the relation between electrical properties of single crystals and their structural and chemical defects was a closely integrated phase of AFCRL's

solid state research program. This study involved theoretical and experimental investigations of single crystals of controlled purity and structure, and such basic crystallographic factors as the atomic spacing and arrangement, the nature of the bonding forces, etc.

#### VERNEUIL FURNACE OPERATIONS:

For a number of years AFCRL experimented with a variety of techniques to grow single crystals of many materials. During 1961, using the familiar flame fusion or Verneuil furnace technique, the Electronic Material Sciences Laboratory grew some 275 single crystal boules, the majority being aluminum oxide (ruby) with a wide range of concentrations from 0.05 percent to 5 percent of chromium, nickel, and other elements. Many chromium-doped boules were prepared for studies of the influence of impurities and structural imperfections on laser activity. A large number of different rare-earth iron garnets were grown from high temperature fluxes in the range of  $1200^\circ\text{C}$  with the emphasis on lutetium iron garnet.

In the search for new and better laser materials, two new ones were tried by laboratory scientists. These were willemite,  $\text{Zn}_2\text{SiO}_4$ , and calcium spinel,  $\text{CaAl}_2\text{O}_4$ . Many experiments were performed in the attempt to get 100 percent conversion starting material to final Verneuil powder. The best that could be done on the willemite was approximately 95 percent conversion. Small single crystals with approximately 95% purity were successfully grown. In the case of the calcium spinel feed material, several methods of preparation were tried without success.

In other experiments, after several unsuccessful tries, during the period  $\text{NiO}$  single boules were grown. One of the biggest problems—the lack of single crystal seed material — necessitated



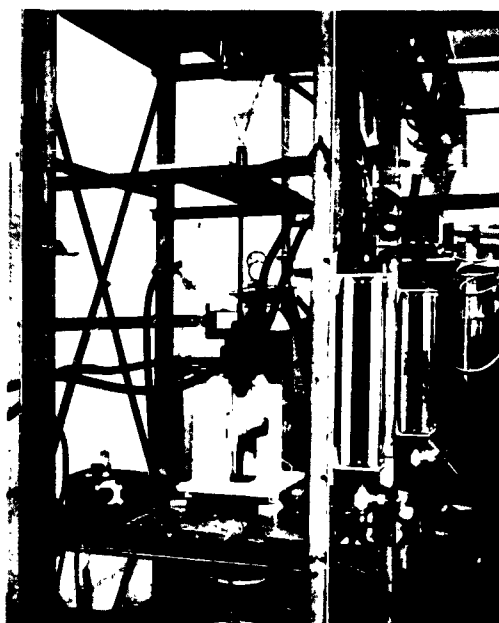
The interior court yard of AFCRL's new Crystal Physical Facility is shown. This facility containing dustproof and vibration-free rooms is one of the most advanced facilities in the country for single crystal research.

careful melting the tip of the cone and growing the boule from it. From the first polycrystalline boule, several single crystal seeds were cleaved and seven single crystal boules obtained ranging from 40 to 60 grams each. A number of these were turned over to an AFCRL contractor for research purposes.

Using the Verneuil technique noted above, however, the scientists were handicapped by the introduction of unwanted impurities into the various crystals through oxidation and outside contamination. To resolve this problem during the period they designed a new Verneuil furnace with a number of

changes incorporated. Instead of the conventional hydrogen oxygen flame, RF energy will be used to dissociate oxygen molecules; the heat generated when the oxygen atoms recombine will be utilized for the growth process. When the new furnace is placed in operation this summer, it should enable the scientists to grow single crystals of a much higher perfection.

The AFCRL crystal physics program during the 1961-1962 period also placed emphasis on: (a) extending the available temperature and pressure ranges to above 3000°C and above 100,000 atmospheres simultaneously and to investigate



Single crystals of rubies, sapphires and rutiles are grown by the verneuil process. The basic material in powder form flows downward to be heated in a hydrogen-oxygen flame. The crystal forms as a boule at the base of the flame.

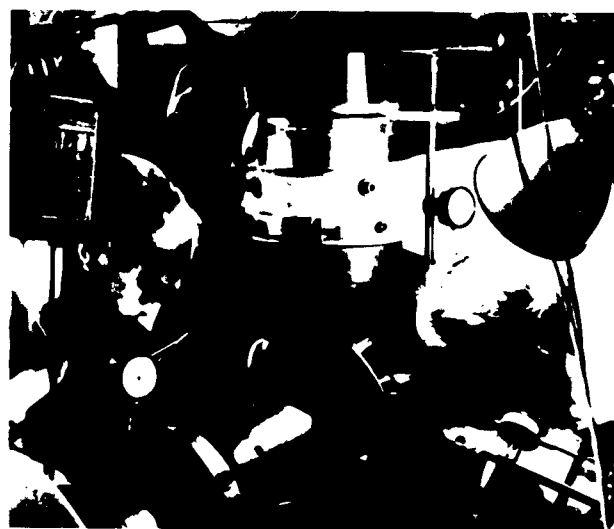
crystals not naturally found on earth and others which are not possible by any other means; (b) growth from the vapor stage to clarify the mechanisms of nucleation and production of crystals in that manner; and (c) study of the effects of chemical and structural imperfections on the formation of the crystal as well as on its electrical properties.

To grow large single crystals of silicon carbide from the vapor phase, construction of a new high-temperature furnace, designed by AFCRL scientists, was begun during the period. A pioneer in the study of silicon carbide as a potential semiconductor material, AFCRL had previously grown small single SiC crystals which theoretically will withstand temperatures up to  $700^{\circ}\text{C}$  compared to only  $200^{\circ}\text{C}$  for silicon. The new

silicon carbide furnace is expected to be operational before 1963.

#### ULTRA-HIGH PRESSURE RESEARCH:

Another material with potential as a semiconductor is carbon in crystalline form (diamond), which has an operating temperature near  $1000^{\circ}\text{C}$  and superior electronic properties. At AFCRL the study of the effects of ultra-high pressure typified by the growth and study of artificial diamonds was begun during the 1959-1960 period. The successful growth of the diamonds (January 1960) was achieved in an ultra-high pressure tetrahedral anvil press, designed and built by AFCRL scientists, which generates pressures in excess of 1,500,000 psi and temperatures over  $3000^{\circ}$ . The basic ingredients have been graphite and a metal catalyst such as nickel; under extreme pressure and temperature, the molten catalyst diffuses through the graphite and the diamond crystals form in that region.



The AFCRL high pressure, high temperature apparatus is used to study materials subjected to extreme pressure. Pressures up to 2 million pounds per square inch can be generated.



Material to be compressed in AFCRL's giant press is placed in the small opening of this tetrahedron. The tetrahedron material distributes the forces evenly over the sample material.

A number of technical problems, however, have arisen with the press, involving measurement methods which have lagged far behind the advances in high pressure generation. Thus the absolute magnitude of the pressures was in doubt; the pressure calibration was obtained by using phase transitions in metals, and indications were that phase transitions were in error by approximately 25 percent. Another problem involved the non-uniform temperatures and pressures generated throughout the high-pressure cavity. During 1961 solutions to these problems were studied and the equipment was modified, which should enable the scientists to determine more precisely the properties of materials under extreme conditions. At the close of the period studies in diamond generation, and of the effects of high pressures and temperatures on other materials, were continuing.

The basic mechanisms of crystal growth by chemical decomposition techniques also were under investigation. The immediate practical aspects of this work involved preparation of precisely-controlled junctions on silicon substrates for use in fabrication of new devices. Many controlled junctions were made during the period, and the process was under sufficient control to permit exploration for device research.

#### **SINGLE CRYSTAL PROPERTIES AND PHENOMENA**

A related and major area of AFCRL research involved the study of the fundamental properties and phenomena exhibited by single crystals. This research was essential both to feed information back to the crystal growth scientists, and to feed it forward to the device research personnel. This area included x-ray crystallography, x-ray fluorescence, x-ray defect studies, electron microscopy, electron diffraction, paramagnetic and ferrimagnetic resonance phenomena, optical transmission and reflection data in the ultraviolet, visible and infrared spectral regions, studies of crystal anisotropy and a wide variety of electrical, optical, and thermal measurements.

It also included microwave measurements on solids, photoconductivity and electroluminescent studies. All of these quantitative measurements both singly and in combination yield the basic information on single crystals of electronically active materials and how their properties can be modified by chemical and structural "defects" to produce useful knowledge and devices for ultimate use in Air Force systems.

**DIAMOND RESEARCH:** One aspect of the above studies of single crystal properties centered on diamond. As was suggested, the advent of diamond syn-



Diamonds are grown on a routine basis with AFCRL's high pressure apparatus. These diamonds, viewed under a microscope measure about 1/25 inch across.

thesis stimulated scientific interest in the fundamental physical properties of the rare species (Type IIb) which is a semiconductor. However, the supply of both natural as well as synthetic diamonds was limited, and samples were sometimes quite small and of irregular shape. These factors combined to impose serious problems in the use of extremely small metal-to-semiconductor electrical contacts when examining fundamental material properties. To avoid these problems "contact-less" techniques utilizing microwave measurements were found quite promising.

During the period these techniques were used by AFCRL scientists to measure the electrical conductivity of irregularly shaped samples of semiconducting diamond, and also were extended to the measurement of other properties such as current carrier lifetime. X-ray diffraction microscopy investigations on conducting and insulating diamonds were pursued, and showed that the dislocation density was widely different for those two classes of diamond. This result as well as the utilization of microwaves for measuring the complex dielectric constant and the electrical conductivity of

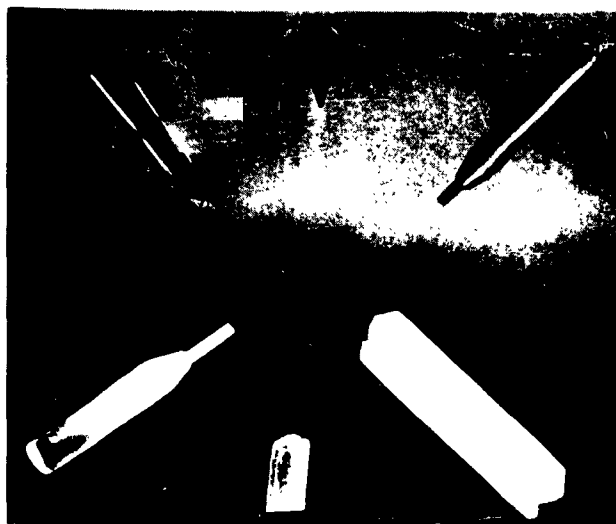
semiconducting diamonds were novel developments. The results of this diamond research were presented at an International Conference on Diamonds, Paris, 1962.

In related work using x-ray diffraction, the oxygen positions in 15 compounds with garnet structures were determined by refinement of the structure parameters. The results of this study were of value for the calculation of crystal field parameters which were of importance to the explanation of paramagnetic resonance phenomena.

**THEORETICAL STUDIES:** Important theoretical investigations were conducted into the optical, thermal and elastic properties of some 65 solids of 16 different lattice structures, and yielded some fundamentally significant results. The outgrowth of previous AFCRL studies in the area of atomic lattice vibrations, these investigations provided new insight into the relations between optical absorption spectra and thermal as well as elastic properties. A fundamental relation between cohesive energy per volume and hardness of the solid was found. It involves the concepts of lattice vibration energy and anharmonicity, compressibility, reduced mass of vibrating atom pairs, interatomic distances and restoration forces.

**MAGNETIC ANISOTROPY:** During the period a program was begun to investigate the origin and nature of magnetocrystalline anisotropy in ferrimagnetic materials using microwave spectroscopy techniques. Since anisotropy is an intrinsic property of all magnetic materials, such knowledge would not only provide a better insight into the basic theory of magnetics and atomic structure, but also would prove to be a considerable boon to those primarily concerned with applications of magnetic materials at microwave frequencies.





Both semiconductor and magnetic materials in single crystal form are grown and evaluated for a host of potential applications — semi-conductors, lasers, amplifiers, oscillators, isolators and so on.

A quantitative investigation of the temperature dependency ( $1.4^{\circ}$  Kelvin to  $300^{\circ}$ ) of the anisotropy parameters was performed on samples of lutetium iron garnet (LuIG) and yttrium iron garnets (YIG), both pure and doped with gallium or indium. Such studies, which were continuing at the close of the period, were expected to be of great help in clearly establishing the role played by the ferric ions on each of its two distinctive lattice sites.

Contrary to an earlier experiment on another LuIG sample, low temperature measurements revealed a similarity in anisotropy behavior of both LuIG and YIG. This discrepancy was attributed to impurities in the former sample.

Single crystal samples of ferromagnetic garnet materials also were studied by the scientists, to determine the intrinsic properties of rare-earth garnets as a function of temperature. The measurement of saturation mag-

netization, anisotropy constants and linewidths of pure rare earth garnets and doped rare-earth garnets provides an insight as to how impurities and/or dopants affect the host lattice.

These measurements were performed for the most part using standard microwave and/or electronic systems. Certain techniques for more refined measurements were developed to increase the sensitivity or "information-gathering power" of these systems when standard techniques were not applicable.

**SPECTROSCOPIC INVESTIGATIONS:** In an earlier period (1959-1960) spectroscopic instrumentation was built for high resolution transmission and reflection measurements on semiconducting and magnetic materials between 2300 Angstroms in the ultraviolet and 36 microns in the infrared. During that period measurements on the lattice vibration and impurity absorption spectra for pure single crystals of silicon carbide were reported at a conference sponsored by AFCRL on SiC.

Subsequently, the optical instrumentation was further developed to include a grating spectrometer capable of extremely high resolution over the same spectral range, low temperature optical dewar equipment, and a spectrometer adapted to photoconductive or radiation recombination studies. Sample holders and accurate positioning equipment were designed to allow scanning of small regions of samples held at low temperatures with radiation from the ultraviolet to the infrared spectral range.

During 1961-1962 studies also were pursued of the band structure of compound semiconductors such as  $Mg_3Sn$  and the impurity levels in semiconducting diamond over a range of temperature. Another investigation of radiation recombination in samples of Si containing impurities which might have some

laser possibilities, was initiated in cooperation with an AFCRL contractor.

#### **THE SEARCH FOR NEW DEVICE CONCEPTS**

In addition to their work on ultrapurification of materials and their research on single crystals, AFCRL scientist during 1961-1962 devoted themselves to intensive investigations of new device concepts which might further advance the capabilities of Air Force electronic systems. This research centered on: (a) single crystals in the form of thin films; (b) the formation and electrical characteristics of p-n junctions formed by the epitaxial deposition of such films for subsequent device and integrated circuitry applications; (c) the mechanisms of surface adhesion to refractory semiconductors (silicon carbide and diamond) in order to understand and reproduce such crystal ohmic contacts with desirable electrical characteristics; and (d) design of basic circuits around devices developing from advances made in the above areas.

**DEVICE FABRICATION:** As part of the AFCRL advance device concepts program, precision techniques were developed during 1961 to enable the



Microthermo compression bonders are used for the fabrication of experimental semiconductor devices.

fabrication of various experimental semiconductor units. This effort was highlighted by the successful fabrication of the latest and most difficult state-of-the-art device, a planar transistor. Among the techniques used were double diffusion, photomasking, photoetching, precision alloying, etc. Following creation of this in-house device fabrication capability, high quality reproducible planar transistors, mounted on conventional headers, were made for device investigations.

In another approach to new device research, a silicon epitaxial deposition process was designed and built which was based on the reduction of  $\text{SiCl}_4$  by hydrogen at 1100 to 1200°C. Deposits for some applications were readily produced, but for more critical applications demanding close control of thickness and impurity concentration, it became necessary to uncover new fundamental knowledge of the kinetics of the reactions involved. Such research was initiated and soon yielded useful information.

For the past few years there has been a continuing strong theoretical effort on quantum mechanical tunneling across extremely sharp p-n junctions, which has yielded useful correlations between impurity concentrations and diode characteristics.

A new device idea that was an outgrowth of the above work is the hybrid amplifier consisting of a tunnel diode in parallel with the input of a common base transistor amplifier. A theoretical device and circuit analysis showed possibility of: (a) current gains greater than one with no resulting change in voltage gain; (b) control over the input impedance level so as to allow higher input impedances and thus facilitate the matching of cascaded amplifier stages; (c) the choice of 0°-180° phase shift between input and output signals. An analog of



High temperature diffusion on thin slices of silicon is accomplished in this furnace. Such diffusion is a basic process in research leading towards improved microcircuits.

such a device was constructed using conventional circuit components; and electrical measurements thereon confirmed the above analysis. At the close of the period experimental work was underway to construct the originally conceived single solid state device which should have a practical application as (1) a small signal high gain amplifier, (2) an automatic gain control and (3) a detector with gain.

In other related work on silicon tunnel diodes, the scientists sought to confirm theoretical calculations regarding the role of degeneracy on device characteristics. This work was based on the growth of silicon junctions from a tin rich solution, at temperatures lower than the melting point of silicon (800°C). Basically during this process an n-type silicon seed was used for drawing p-type material out of the tin. Extremely abrupt junctions, suitable for tunnel diodes, were grown because the diffusion

(penetration) does not cause junction broadening at those temperatures.

In general, the Laboratory during the period concentrated on majority carrier devices as the most probable answer to active higher frequency devices adaptable to multiple processing for integrated systems. The severe, critical material requirements of conventional minority carrier devices made the simultaneous construction of thousands of perfect devices on a common substrate quite unlikely. In addition to the tunnel emitter amplifier previously mentioned, theoretical and experimental work was pursued on the development of a majority carrier thin film tunnel amplifier utilizing polycrystalline material and also on a more conventional unipolar field effect device of a new design suggested by the successes of the new epitaxial film technology.

#### **RADIATION EFFECTS ON ELECTRONIC MATERIALS**

The organization's solid state research program for several years also has encompassed a study of the effects of the numerous energetic radiations found in outer space or from nuclear power sources. It became clear that, in addition to their dangerous effects on personnel, such radiations might produce various degrading effects on the space craft's electronic gear as it travelled through the Van Allen radiation belt (magnetosphere), through proton showers emitted from the sun, or from its own power source. Evidence accumulated that the physical and chemical properties of electronic equipment would be changed through ionization and displacement, but detailed knowledge of the extent of the effect and whether it could be prevented or minimized, remained largely unknown.\*

\* For other aspects of AFRL studies of solar radiations, see Chapter VII.



Thick walls and doors protect scientists from radiation generated by AFCRL's 3 MEV Van de Graaff Generator.

#### THE AFCRL RADIATION COMPLEX:

To accumulate new basic knowledge of these radiation effects the Air Force Cambridge Research Laboratories completed the construction of a new radiation complex at Hanscom Field during the period. This facility consists of a 7200 curie cobalt-60 source, a three million electron volt Van de Graaff positive ion accelerator, and a high current 1.2 million electron volt Dynamitron Electron Accelerator. The final acceptance test on the cobalt-60 source was completed on 13 September 1961. In combination, these sources constitute an outstanding tool for conducting radiation effect studies in a controlled environment.

Earlier, during the 1950s, the main orientation of such studies involved consideration of radiations from nuclear reactors and weapons. Scientists gained some limited experimental knowledge by observing changes in materials exposed to radiations inside a nuclear reactor. However, this data remained difficult to interpret in terms of fundamental

internal events because of the complex spectrum of neutron energies and gamma ray energies present in the reactors. In general it became clear that there were two types of events of importance insofar as nuclear effects are concerned — ionization and atomic displacement. The latter was accompanied by the former but ionization was not always accompanied by displacement. That is, gamma rays produced ionization but atomic displacement usually did not occur if the energy level of the ray was less than some minimal (threshold) amount.

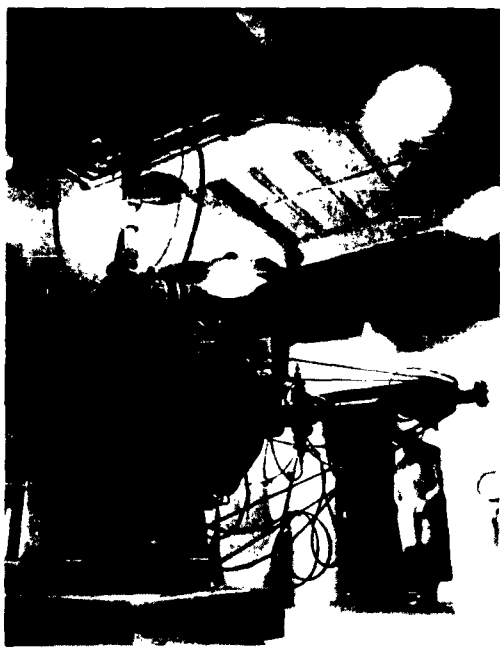
Aside from these generalizations, fundamental knowledge was lacking on how the radiation moved the atoms about, what the range of movement was, what energy levels were produced, and how permanent were the changes. Even



A Cobalt-60 source of 7,000 curies is used to irradiate various materials and components to determine the effects of gamma radiation on the material.

with AFCRL's new irradiation facility example, even with monoenergetic beams, the problem of interpreting structural changes remained formidable. For example, even with monoenergetic beams, scattering can occur within the irradiated specimen and its surroundings leading to a spectrum of radiation energies which must be calculated or measured. There was, in addition, a related problem involving the difficulty of observing the effects created. Because of their ultra-microscopic nature, the only means of determining their effects and number was by measurement of changes in chemical and physical properties.

The AFCRL irradiation studies began with low temperature electron bombardment of pure crystalline material, using



High energy protons generated by a Van de Graaff Generator located on the floor above are deflected by this huge magnet 90 degrees from their original course. The material to be irradiated is placed before the opening of a horizontal tube.

electrons in the vicinity of one million electron volts. These transferred just enough energy to displace single atoms, avoiding the complications associated with atomic cascades. Low temperatures in the vicinity of 10° Kelvin were used to freeze in the primary defects before they had an opportunity to interact with one another or with imperfections already present. Damage then was observed through changes in electrical resistivity.

To measure the damage, AFCRL personnel designed and assembled special instrumentation that included: a liquid helium irradiation dewar suitable for carrying out isochronal and isothermal annealing studies of irradiated specimens; thermometry apparatus for measuring the low temperature involved; resistivity equipment capable of detecting potentials as small as 0.01 microvolts; and apparatus for measuring and controlling the electron beam.

Studies also were begun on the damage produced in single crystals by monoenergetic neutron beams. Equipment has been assembled to measure damage production rates as a function of neutron energy. The measured rates will be compared with values calculated from present theoretical models, and then later identified, if necessary, in order to establish a reliable basis for predicting and perhaps controlling the nature and extent of the effects produced. These efforts, which were just beginning to pick up momentum during the first half of calendar year 1962, seemed certain to advance scientific knowledge of the complex chain of internal events set in motion in materials when struck by external radiations.



The AFCRL programs in the earth sciences, which encompass such fields as geology, glaciology, geodesy, and seismology, during the period generated important new geophysical information that may directly affect the nation's strategic air and ICBM forces. Conducted by personnel of the Terrestrial Sciences Laboratory, these programs centered on studies of various inaccessible areas for possible emergency landings and takeoffs of heavy bombers, on new geodetic techniques that may facilitate long range missile strikes, and on development of a U. S. capability to detect underground nuclear explosions.

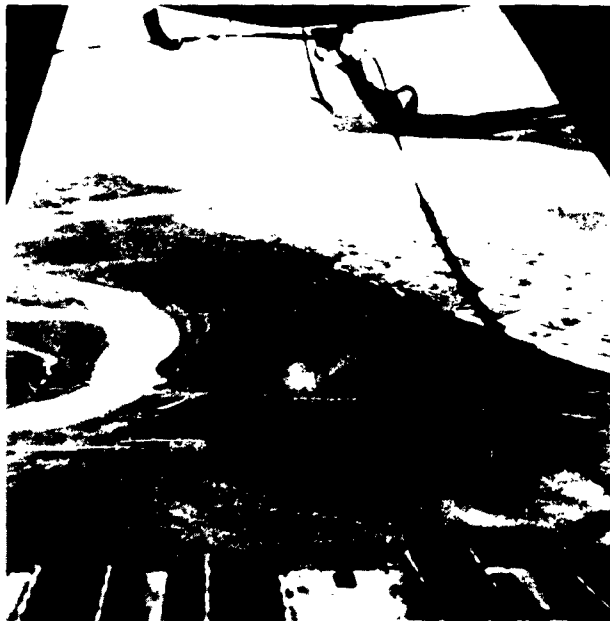
#### **EARTH PHYSICS AND THE DETERRENT FORCES**

With modern-day weapons becoming increasingly efficient and devastating, the availability of adequate areas for effective dispersal of Air Force retaliatory elements has become an important military problem. In the search for greater security for these forces to enhance the nation's second-strike capability, AFCRL scientists have studied the vast unpopulated and unattractive regions of the Earth's surface for possible Air Force operations. This research, which began in 1955, has centered on the polar regions, on the unpopulated temperate zone areas, and on the arid and semiarid regions of the globe.

The basic AFCRL investigations have been directed toward understanding the chemical and physical properties and distributions of various crustal materials in the inaccessible areas. Such

materials include consolidated rock (igneous, sedimentary, metamorphic), unconsolidated rock (gravel, sand), and soils, ice, and snow. Under special circumstances, it has been found that many of these materials are capable of supporting the landing and take-off of heavy aircraft.

**PROJECT ICE WAY:** One of the most dramatic evidences of this was demonstrated during Project Ice Way, a five-month research and engineering field program which involved the successful landing and take off of Air Force planes from natural sea ice in the North Star Bay near Thule, Greenland. This project, conducted in early 1961, was based on earlier AFCRL research into the structure and properties of sea ice and



Aerial view taken in the Centrum Lake area of Northeast Greenland shows sandy terrace which provided an ideal natural landing area. Photo was taken from the rear of a C-130 aircraft resupplying the AFCRL operation by airdrops.

constituted a joint effort with the U. S. Naval Civil Engineering Laboratory.

The field program involved the construction of a 14,000-foot runway on natural sea ice which, aside from the removal of a snow cover, was not processed or built up in any manner. Besides the runway, parking pads, a test pit and four load tank installations were constructed, using fiber-glass reinforcement during flooding of several of the pads and the test pit. This reinforcement, later tests showed, produced a tenfold increase in the strength of the ice.

The major portion of the work was accomplished during February and early March 1961. Beginning on 14 March, six currently operational aircraft (a C-47, F-102, C-130, B-47, KC-135 and the 214,000 pound B-52) participated in tests of the natural and processed sea ice platforms. Each plane made several landings and take-offs along the natural ice runway, and parked for periods of up to two hours on the runway and the processed parking pads. Several planes also made taxi runs at various speeds along the runway.

The fact that some of the heaviest aircraft in the Air Force inventory actually landed and took off from the sea ice on North Star Bay was physical proof that the area, and similar areas, could be used for emergency aircraft operations. Pilots of the test aircraft were unanimous in their opinion that the braking action of the ice runway was better than that of the main runway at Thule, and that the ice surface was as smooth as many paved surfaces they had landed on.

During this operational phase, data was collected on the static deflection of natural ice and the processed ice platforms, on creep characteristics, and on the ice's elasticity, electrical properties,

crystal structure, temperature, salinity, density, etc. The collection of data was largely completed during April; however, the site was not abandoned and the project terminated until 31 May 1961 when the ice reached a state of advanced deterioration.

While Project Ice Way was the most dramatic of recent AFCRL studies of natural landing sites, earlier investigations also had added to Air Force knowledge of the utility of the northern regions. In particular, during the May-August 1960 period the laboratory investigated ice-free natural land areas in north and east Greenland for possible use as emergency air-strips. The detailed scientific field program included studies in geology, soil engineering, permafrost, meteorology and electrical resistivity of soils. Successful test landings by heavy type aircraft such as the C-119 and C-130 were made on an

airstrip improved only by scraping, dragging, and rolling operations.

During the 1960 Greenland field experiments, seeking additional knowledge of permafrost, AFCRL scientists devised a technique to record the variations in electrical resistivities between frozen and unfrozen soil and between soil and water. Depths to the upper level of the permafrost, measured by this technique, varied by only three percent from those obtained by drilling. These encouraging results warranted further experimentation, and during 1961 studies were initiated to develop suitable lightweight portable equipment for use in rigorous environments. Such equipment could enable personnel to quickly identify at any location the upper level of permafrost, and the desirability of various sites for Air Force utilization.

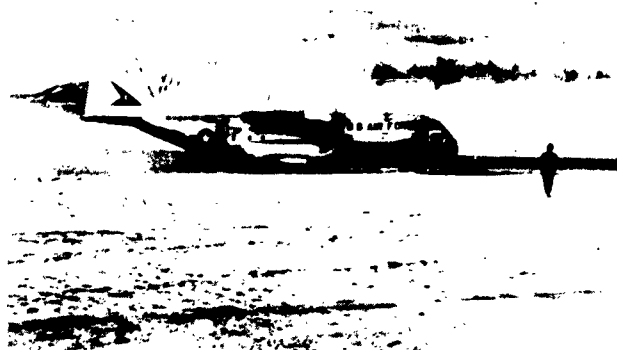


Natural ice, properly treated, can support the heaviest aircraft in the Air Force inventory.



**QUICK CLAY RESEARCH:** The AFCRL search for potential landing sites during the period also included contractor investigations of land areas containing "quick clay" deposits. These deposits were found to be highly sensitive, unstable and potentially dangerous in their natural state. On certain occasions, upon slope failure, quick clays in the past have destroyed life and property without warning. A landslide of this type occurred at the town of Rimouski, Quebec, and was attributed to the material's reduced electrolyte content, artesian water pressure, and the relatively steep slope of a nearby bank. The AFCRL-sponsored research was directed toward the possible strengthening of the structure of quick clays through spraying of various solutions.

Related contractor studies encompassed the clay mineralogy of the dry lake beds known as playas. The worldwide occurrence of these virtually featureless dry lakes, which number about 300 in the United States alone,



A C-130 aircraft turns around after landing on natural sandy terrace at Centrum Lake. The terrace provides a broad, smooth, hard landing strip.

makes them potentially useful as landing sites. The initial work in this area involved the collection of more information on their distribution and composition.

The geomorphology of the arid and semi-arid regions of the world also were targets for the AFCRL data collection effort. An intensive search of the geophysical literature was conducted during the period, and a compilation begun of existing photographs and maps of various deserts and soils. A number of arid Middle East and North African countries in particular were selected for study, with a view to relate them to analogous areas in desert regions in the western United States. Photogeologic methods were adopted for selection of sites inherently suitable for unprepared landing areas and to analyze ground conditions; these were



Polarized light passed through a thin section of ice was used for the microscopic examination of ice crystal structure, one of a score of techniques used to determine properties of the sea ice.

to be subsequently tested by actual light and heavy aircraft operations.

Since it became essential to develop a systematic data collection program over diverse and often inaccessible areas of the world, AFCRL examined the possibility of using various airborne sensing devices. A thorough evaluation of available sensing systems was made, while investigations were begun into new ones. The possible use of radar and infrared techniques to determine terrain properties were examined, as well as use of pulsed radio-frequency energy for measurement of the conductivity and dielectric constants (for indications of moisture content in the top layer of the soil). Several of the sensing instruments showed promise and were scheduled to be installed in the C-130, together with precise navigation equipment and aerial cameras, for field testing.

Besides those activities, other investigations by AFCRL concentrated on the composition and distributions of tropical soils or laterites (i.e., soils in which the silica is removed by deep chemical leaching, leaving gels of iron and alumina behind). In wet situations the laterites provide severe restrictions on any kind of vehicular movement. Efforts were made to develop techniques for identifying laterites from aerial photographs, to enable scientists to determine their world-wide distribution.

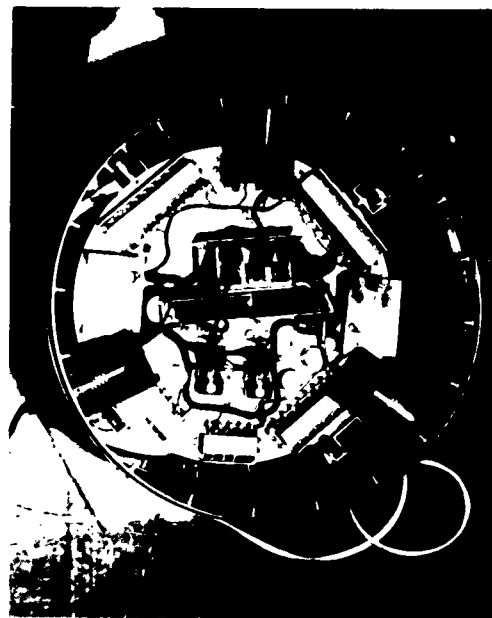
#### GEODETIC RESEARCH PROGRAMS

The advent of intercontinental ballistic missiles and earth satellite systems not only generated the most stringent geodetic requirements of all time, but concurrently provided the geodesist a means by which those requirements could be met. Air Force needs in this area include: a capability to measure distances between selected global points within an accuracy of inches and feet

rather than hundreds of feet; obtaining more precise information on the earth's shape; determining the locations, magnitudes and intensities of large gravity anomalies; and developing a coordinate system with the capability of relating all geodetically significant positions in a uniform manner.

#### ROCKET-FLASH TRIANGULATION:

Research in this area was undertaken by AFCRL with contractor support, and was primarily oriented toward the design and development of new techniques for geodetic positions determination. During 1961 the most active research revolved around a rocket-flash triangulation technique that had been first suggested by a Finnish geodesist. Its objective was to extend classical

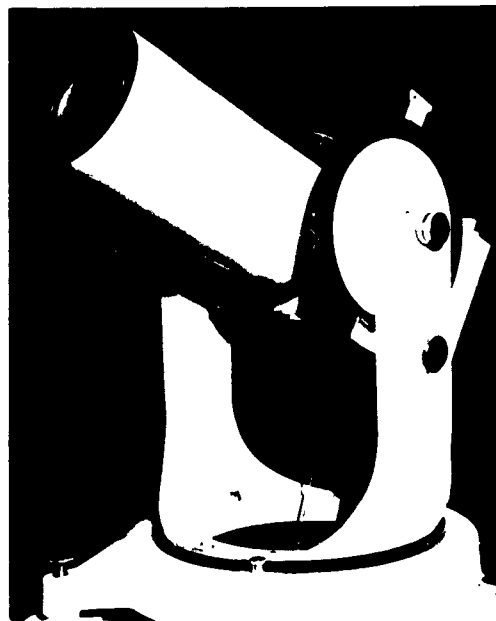


Basic payload carried by Astrobee 1500 rocket for flash triangulation experiment consisted of three canisters spaced at 120° intervals on the skin of the rocket vehicle. Each canister contained seven "Poppy" photo-flash cartridges. Also shown are the timing mechanism and detonating equipment.

surveying to three dimensions by photographing flashes carried aloft by a rocket against a star background. The photos were to be made simultaneously from at least two camera sites where geodetic coordinates were accurately known, and from other sites treated as unknown. Then by measuring the images of the stars and the images of the rocket flashes as recorded on the photographic plates, it appeared possible to fix spatial coordinates and to triangulate from the known to the unknown positions. This interesting technique promised a number of advantages over classical methods, including the fact it could jump large water distances and ignore anomalies in the gravity field.

The most important test of this rocket-flash triangulation technique was conducted by AFCRL the night of 8 December 1961, during the launch of an Astrobee 1500 rocket from Point Arguello, California. The rocket carried a special rocket-flash payload consisting of 21 high intensity short duration pyrotechnic flash cartridges (developed by U. S. Army Ordnance, Picatinny Arsenal, Dover, New Jersey). Each of the flashes was capable of producing a peak light output of 62 million candle power. The experiment was programmed so that seven flash cartridges would eject at various heights, the first set at about 900 miles, the second at apogee (roughly halfway between California and Hawaii), and the last set again at 900-920 miles elevation.

To record the flashes, specially designed geodetic stellar cameras were stationed along the west coast of North America: at Sitka, Alaska, Spokane, Washington, and Lincoln and El Centro, California, and in Hawaii at Mauna Loa and Kaena Point. Possessing extremely long focal lengths, the geodetic cameras



The AFCRL Geodetic Stellar Camera PC-1000 was used to photograph flares released at high altitude against a star background. By triangulation techniques, distances between land masses can be determined with great precision.

were capable of producing very accurate stellar images on precision-ground photographic plates. As part of the experiment, other instruments also were used at sites in New Mexico, California, Hawaii and Johnson Island. They included Baker-Nunn cameras and a Minitrac camera. Four astronomical observatories and a U. S. Navy Hydrographic Office ship camera also were involved. On the night of 8 December the rocket was successfully fired. Unfortunately, poor weather over certain areas and mechanical failures reduced the amount of photographic data obtained. Nevertheless, it was considered the experiment had demonstrated the feasibility of using the rocket-flash triangulation technique to define the relative positions of various participating sites.

**PROJECT ANNA:** A natural extension of the above technique involved the use of satellite-borne optical beacons, a method whose potentialities had been studied by AFCRL scientists since 1958. During the 1961-1962 period AFCRL contributions towards the launching of a Department of Defense geodetic satellite (Project ANNA) included the complete redesign of the initial, self-contained stroboscopic light. On the ANNA satellite, the strobe lights are mounted in pairs diametrically opposite each other on the north and south flanges. Power is drawn from solar cells and nicad batteries, charging capacitors to activate the flashing of the lights over selected sites around the world. Because of rocket difficulties, the first satellite launched on 10 May 1962

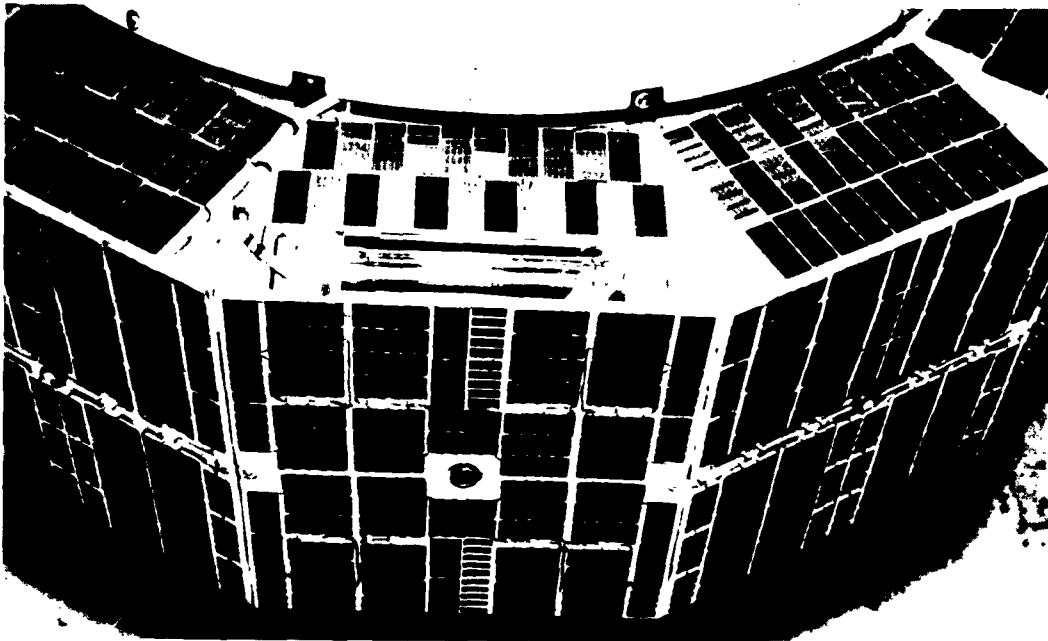


The ANNA satellite was designed to improve our knowledge of the size and shape of the earth. The sphere with its solar cell belt will permit the simultaneous observation of ranging, range-rate, and optical measurements. On the top and bottom of the solar cell belt are the ANNA flash tubes.

failed to go into orbit. A second ANNA launch was scheduled for the summer 1962.

Early AFCRL experiments with the flashing light device had centered on the degree of visibility at observing sites as the satellite changed altitude, both horizontally and vertically, and the operational capability of photosensor equipment used with geodetic stellar cameras. During November 1961, with contractual assistance, an experiment was conducted to record photographically changes in apparent magnitude of the light output (from a simulated satellite) with changes in vertical and horizontal angles relative to the line of sight. In this experiment a new photosensor unit was mounted atop one of the main AFCRL buildings at Hanscom Field, while a working model of the satellite light system was transported to Mount Wachusett, 47 miles away. During the test various changes of elevation angle and horizontal angle were applied to the light. Coupled with the extreme variations in weather conditions at the time, these changes demonstrated that the photosensor system was capable of monitoring the orbiting satellite and its electronic flash system.

In the course of research into new geodetic techniques, AFCRL personnel also hit upon a method of using passive reflectors, satellite-mounted, as optical beacons for geodetic data acquisition. This technique required the sending of a very powerful narrow beam of light from each optical observing site to a prismatic reflector on an orbiting satellite. Suitable ballistic cameras or geodetic stellar cameras, mounted at each site in conjunction with the light source, would then photograph the light reflections against stellar backgrounds. Then using stellar triangulation computations, the relative positions of many



This close-up view shows one of the four ANNA satellite flashtubes. The flashtubes will permit geodesists to make accurate angular measurements by photographing the flashes against a background of stars.

widely scattered geodetic observing sites could be established. An important advantage of this technique was that the bulky power systems mounted in satellites to generate light signals, could be replaced by the relatively light prismatic reflectors or prismatic reflecting material.

To test this concept, a camera and light source were mounted on the roof of an AFCRL building in March 1961, and a sizable retrodirective mirror emplaced atop Mount Wachusett. Attempts were made to bounce a light signal from the building to the mirror and back to the camera to see how the dispersion of the light and light intensity would be affected by the then severe atmospheric conditions over the area. The experiment proved to be partially

successful, and encouraging enough to warrant further exploration of the technique with equipment more appropriate to operational needs. These investigations were continuing at the end of June 1962.

#### **LONG LINE AZIMUTH DETERMINATION:**

Still another promising area of geodetic data acquisition involved a method developed by AFCRL scientists known as the "Long Line Azimuth Determination Technique." This method was designed to furnish precise azimuths between non-intervisible geodetic stations. Basically, the approach consisted of mounting a high intensity stroboscopic light on an aircraft flown on a course roughly normal to the line between two non-intervisible points. Line crossing was to be accomplished

at several elevations, and cameras were to be stationed at two sites for which azimuths were desired to constantly record the light flashes against a stellar background. Subsequently, the position of the flashes from each site could be computed, and from these the relative directions between the two sites established.

On 9 and 13 January 1962, AFCRL personnel tested the technique during flights made in cooperation with the Aeronautical Systems Division and the Air Force Missile Test Center. A B-58 aircraft, flying at altitudes of 25,000 and 35,000 feet, made several line crossings between non-intervisible observing sites at Vero Beach and Homestead, Florida, and at West End, Grand Bahama Island. During this time photographic records of the flashing light and the line crossings were made. Weather once again played a disruptive role in reducing the total amount of data collected. However, sufficient data were generated both in quantity and quality to demonstrate the technique was feasible for establishing longline azimuths. At the close of the period, additional work on improving the power of the flashing light equipment was continuing.

A noteworthy aspect of the above activity was the AFCRL mathematical studies conducted in order to develop the formulae for computing the azimuths. Thus, formulae were derived for determining the forward and back azimuth between non-intervisible distant points, using the geodetic stellar observations. An initial problem in this research dealt with short distances, and required a solution that could be handled on a grid system such as the Universal Transverse Mercator Grid, where the observed quantities could be adequately reduced to a rectangular azimuth without sacrificing distances.

A second problem involved extending the first solution to longer distances: it was resolved by line crossing methods when only azimuth data were collected (and the procedure became iterated to establish convergence) and by a method where both azimuth and distance data were obtained.

A third mathematical solution toward computing the azimuths involved the space extension of the first two solutions. In this case, the topocentric right ascension and declination of the light source were measured, instead of local direction and azimuth, and the solution became independent of flight path or time of crossing.

This mathematical research was only one small phase of similar activity which involved satellite and multi-angulation tri-dimensional calculation using computers. During the period special computer programs were set up to: (a) generate satellite observation data; (b) define orbit calculation (two variations being investigated); (c) advance photographic plate reduction programs; and (d) compute three dimensional, multi-angulation and multi-lateration for geodetic ties.

The first of these computer programs involved satellite observation prediction based on a magnetically-oriented satellite with specific cone angles of illumination. The program included all perturbing forces due to bulge, drag, etc., to maintain rigid acquisition specifications for long focal length cameras. The second computer program involved a differential correction process centering on variation of parameters to account for significant perturbation to fit the orbit for geodetic accuracies. The program also derived geocentric positions of observation sites from predicted space positions of the satellite, aiming at producing the best fit, and consequently the most logical

correction to the orbit, station position and potential coefficients which most nearly represented the observed data.

The third computer program involved the reduction of photographic data, and was designed to extract the ultimate in metric accuracy for small field-of-view cameras used in geodetic applications. This program allowed for the inclusion of stellar breaks relative to star images, took into consideration positional errors in star coordinates, treated refraction errors in several ways to adequately handle low elevation observations, and established uncatalogued star positions to 0.5 seconds of arc from one plate. The fourth computer program was designed to include range measurements as well as optical data.

#### **THEORETICAL AND APPLIED GRAVITY RESEARCH**

During the 1961-1962 period AFCRL scientists were deeply engaged in both theoretical and applied research into the earth's gravity field and physical geodesy. One product of this research was the development, together with computational methods, of a theory for normal (theoretical) gravity and the gravitational field of an ellipsoid of revolution. Closed formulae and power series, to compute any parameter of the normal field at any elevation, also were studied and a set of new gravity formulae was computed from free air and isostatic anomalies. Different methods were developed for computation of the continuation of the anomalous field to high altitudes, and for interpolation and extrapolation of gravimetric quantities in the earth's gravitational field. A statistical analysis of the different types of anomalies, using selected representative observations, also was pursued during the period. It was expected that by 1963 an important outgrowth of this research would be

an AFCRL recommendation to replace the present International Gravity Formula.

As indicated, a significant portion of the AFCRL theoretical research was directed toward establishing a uniform, absolute "world gravity system" to which all gravity observations could be referred. This work also was aimed at the establishment of a "world calibration system" and uniform values for the unit of gravity acceleration (milligal) observed by different instruments throughout the world. To accomplish this, a requirement existed for new determinations of absolute gravity using different methods and instruments, and for long range relative measurements between absolute and calibration stations.

The search for new methods of measurement (see discussion below), and the theoretical studies of the earth's gravitational field, were of direct and primary interest to the Air Force. Thus, for example, the effect of the errors in the geodetic and geophysical parameters on ICBM guidance systems



Relative pendulum apparatus, designed by AFCRL, will be used in the re-evaluation of gravity reference values.

were studied, and it was determined that the gravitational disturbances along the trajectory of a missile could have a significant effect on the point of impact or CEP (circular error of probability) of the warhead. At the end of June 1962, the effects of the total geodetic/gravitational error on missile CEP's remained under study, with the AFCRL goal being the development of qualitative and quantitative gravity information for use in the guidance of any given missile weapon system.

**AIRBORNE GRAVITY METER SYSTEM:**

In the case of gravimeter techniques, AFCRL previously had developed (1958) the first airborne device for rapid acquisition of gravity data on a global scale. During 1961 this research was directed toward a complete repackaging of the prototype gravity meter. The new configuration promised greater accessibility to the various components, and should considerably facilitate the transportability of the entire airborne gravity meter system. At the same time, a new airborne gravity meter system was developed which had the desirable feature of being somewhat smaller than the prototype.

Both systems were scheduled for simultaneous testing to determine which was more suitable for ultimate operational use. These airborne comparative tests began over Edwards AFB, California, in April 1962. A more thorough test program, which was expected to take approximately 18 months, was to include flights between Germany and Japan along the 45° north parallel, over the North and South Poles, and completely around the Equator.

Anticipating a vast amount of information would be generated by the airborne gravity program, AFCRL

scientists also sponsored research aimed at facilitating handling and data reduction. A major contractual effort in this area was designed to provide a fast and accurate method of applying and evaluating inputs of information and computing actual gravity values as the end product of all the airborne research. Special emphasis was placed on devising a "quick look" data evaluation method so that air crews could immediately determine whether a given flight had produced usable data. If not, new flights could be made at once rather than wait for a later evaluation, which might call for repeat missions at a less convenient time.

Since any international gravity network would require a reference to some absolute value of gravity, and because of the scientists' concern that existing gravity reference values might be inadequate, special attention also was given during the period to developing new instrumentation to produce such data. New values, if obtained, could be considered a United States contribution toward the more precise determination of an absolute gravity system. The design and fabrication of a reversible pendulum apparatus for making measurements was one phase of AFCRL research in this area. For world-wide surveys requiring comparison tests of pendulum gravity measuring devices, another new, relative pendulum apparatus also was designed. Two sets of the latter were nearing completion at the close of the period, and were to be field tested in the immediate future.

Other laboratory work in the field of gravimetric techniques included the development of an Ice Island Gravity Meter, which demonstrated a capability of measuring and recording long period changes in relative gravity as might



occur on an oscillating platform. During tests of this device, it was found to have a capability for measuring earth tides.

The application of geodesy research progress to the exploration of the aerospace environment as a whole, and particularly for manned lunar landings, also interested AFCRL scientists. It had become clear that American astronauts, if they were to navigate throughout aerospace with any degree of certainty of distance, direction and location, would require precise space referencing systems and charts of the moon and the planets. With this objective in mind, AFCRL personnel participated in a USAF Horizontal and Vertical Lunar Control study to develop a functional system of fundamental lunar reference points to which Air Force lunar charts could be tied (as well as lunar hypsometric data for moon contouring purposes). As part of this research, AFCRL supported basic studies at the University of Manchester, England, at the Paris Observatory and the Lunar and Planetary Laboratory at the University of Arizona. In-house investigations also were initiated to design and develop lunar transponder and gravity sensor devices to determine positions on the lunar surface.\*

#### **SEISMOLOGICAL STUDIES**

Another important part of the AFCRL mission was its continuing research efforts to devise a reliable system for detecting and identifying underground nuclear explosions. In cooperation with other Department of Defense organizations engaged in the Vela-Uniform research program (sponsored by the Advanced Research Projects Agency), the AFCRL studies were directed

toward exploring and developing useful techniques to detect, locate and identify various military explosions or operations capable of generating vibrations in the earth or atmosphere.

**THE AFCRL PROGRAM:** AFCRL seismological research was divided into two broad areas: (a) generation and propagation of seismic waves; and (b) detection methods and instrumentation. In the first instance, the scientists concentrated on the mechanism of seismic wave generation by earthquakes and explosions. Involved were such considerations as the effects of focal depth, energy and spectral distributions among various kinds of elastic waves, radiation patterns at the source, the effect of structures on propagation, and the use of inverse transformations to reconstitute source waveform.

Examining various detection methods and instrumentation, AFCRL scientists sought to determine whether they could differentiate nuclear detonation signals from background noise, earthquakes and chemical explosions. These studies involved examination of signal and noise characteristics and methods of maximizing signal-to-noise ratios, experiments with deep-hole detection techniques and large surface arrays, ocean bottom detection techniques and instrumentation and data processing and display.

One series of field tests, designated Project Cowboy, included eight chemical explosions at an Atomic Energy Commission test site. During 1961 analysis of the AEC tamped and decoupled shots led to significant conclusions concerning the energy transmitted and the spectra of the seismic waves produced. For example, the data showed that the predominant energy of decoupled signals was concentrated in the first few arrivals, whereas

\* For other aspects of AFCRL space studies, see Chapter VII.

the tamped signals were characterized by many arrivals of constant amplitude. The tamped shots also transmitted a greater quantity of low frequency energy.

Other field tests involving chemical explosions were directed toward a study of shear waves (SH) polarized in a horizontal plane. Analysis of data obtained showed that: (a) the SH motion was a normal and expected result of an underground explosion; (b) the model of an underground explosion (as a spherically symmetrical center of compressive stress) was an oversimplification and could not explain all the features observed on seismograms; and (c) the formation of cracks radiating from the crater zone was a likely source of SH generation.

In December 1961 a series of additional tests were conducted in a 10,000-foot well near Hobart, Oklahoma, to determine whether the signal-to-noise ratio could be increased by recording at depth (because of the decrease in surface noise). With measurements taken at regular intervals, it was found that the surface noise level decreased to a depth of 7,500 feet, remained fairly constant to a depth of 8,500 feet, and actually was higher at 10,000 feet. Attenuation of the surface noise appeared to be related to the velocity curve which showed seismic velocities increasing regularly to a maximum between 7,000-8,000 feet, and then decreasing over the next 2,000 feet.

During the period records from earthquakes, quarry blasts, and other chemical and nuclear explosions also were analyzed in an attempt to obtain Fourier transforms and power spectral density estimates of seismic signals as a function of distance, magnitude and type of source. A series of controlled quarry blasts recorded at a distance of 900 feet demonstrated the effect of

ripple firing on amplitude and spectra of the seismic waves. A measurable reduction in the amplitude of compressional and shear waves was observed at some frequencies.

Analysis of the polarization of shear waves received from Kamchatka earthquakes, at stations distributed azimuthally about the source, showed: (a) the occurrence was common of earthquakes in which the first motion of the dilational wave (P wave) was a compression in all quadrants and the shear wave was polarized in the vertical plane; (b) the mechanism generating the S wave repeated itself from earthquake to earthquake; (c) the observed P and S motion indicated thrust faulting; and (d) 22 of 23 earthquakes examined indicated a double couple as

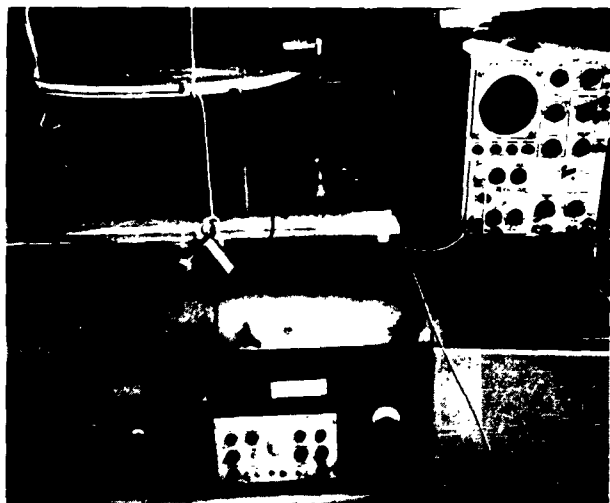


A plastic disc is used in model studies of seismic energy distribution. An earthquake producing fault was simulated by freezing a displacement in the plastic disc and then permitting it to thaw. Forces set up by the displacement during the thawing process produce seismic waves in the disc.

the source mechanism. Other earthquakes also were studied for pertinent data during the period, using a large library of seismograms recorded on magnetic tape that was collected by AFCRL.

In related theoretical and laboratory model studies, the energy distribution resulting from a radial source, a single force, a single couple, and a double couple, also was investigated. On examining the double couple, actual fault displacements were created in the models by "freezing" a stress in them. When heat was applied, the fault snapped back to its original position, releasing energy in the form of elastic waves. This technique produced an "earthquake" in the model more real than expected, in that it was accompanied by fore-shocks and after-shocks.

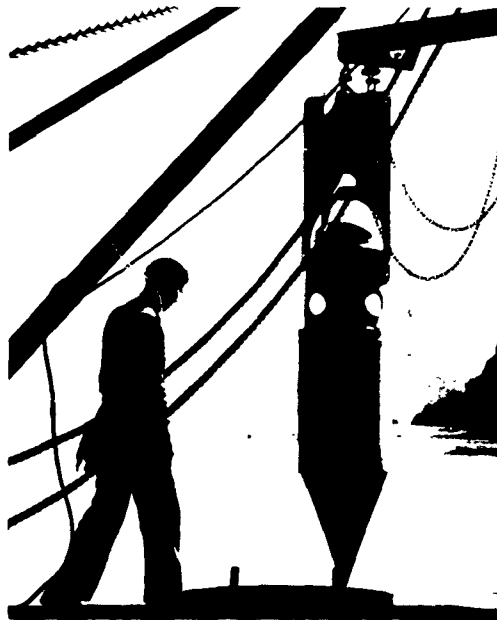
In another area the yield stress and plastic flow properties of rocks under conditions of high hydro-static pressures and temperatures were studied, to provide an understanding of the mechanics of coupling of underground



This apparatus is used for detecting seismic energy distribution from different types of sources, both man made and natural.

nuclear explosions to the surrounding medium, and the source mechanisms of earthquakes. A theoretical solution to the two-dimensional wave propagation problem was developed, with verification being sought in laboratory model experiments.

To measure ocean-bottom seismic phenomena to depths of 10,000 feet, an automatic marine seismic monitoring and recording device was developed during the period. This device senses, amplifies and records in digital form on magnetic tape seismic signals in the one to ten cps frequency band, and appeared capable of responding to vertical and/or horizontal earth movements of less than a millimicron. During initial tests of this new device, in January 1962, seismic events were recorded off the coast of California.



Automatic marine seismic monitoring and recording device contains a 3-component seismometer system and pressure detector capable of recording seismic events on the ocean floor to depths of 10,000 feet. Photo was taken off Catalina Island.

Q Much of electronics can be collected under the general heading, electromagnetic wave sciences. Under this heading falls AFCRL research concerned with the generation, radiation and collection of EM energy. Also included are measurements of the pathways taken by the energy through the atmosphere and space, and studies of those influences which absorb, reflect, perturb or degrade the EM signal. Research at AFCRL embraces much of the electromagnetic spectrum — from extremely low frequencies at one end through the VHF and UHF regions to the optical and ultraviolet region at the other. All of this work is related to the basic Air Force research goals of improved communication and detection.

During the 1961-1962 period four key AFCRL groups were committed directly to extending Air Force communication and detection capabilities through research in the EM wave sciences. They included: the Electromagnetic Radiation Laboratory, Propagation Sciences Laboratory, Communication Sciences Laboratory, and Detection Physics Laboratory. These groups pursued scores of investigations of new and potentially superior concepts and techniques for the reception and detection of electromagnetic energy, and the propagation of such energy through various media. Their noteworthy achievements during the period included:

A new AFCRL design for construction of super-large aperture antennas with high resolution capabilities; pioneering work in non-linear antennas and data processing applied to partially coherent electromagnetic waves; a new

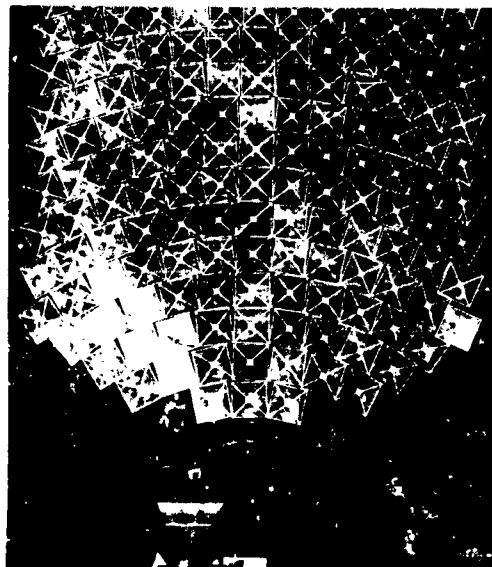
technique for magnetic pulsing low loss ferromagnetic materials to produce higher frequency radiation; a good start in the exciting area of optical device research; successful demonstration of techniques for long range air-ground scatter communications; and significant progress in over-the-horizon detection of aerospace targets.

An important portion of the organization's work in the electromagnetic sciences, which may be mentioned in passing, involved AFCRL's participation in the U. S. nuclear tests in the Pacific. Sixty scientists from the laboratories were engaged in these experiments during the spring and summer of 1962. Earlier, during the nuclear tests of 1958, the Cambridge Research Laboratories pioneered in the measurement and study of the various disruptive effects on radar and radio communications caused by high altitude nuclear explosions. In this report, however, only the unclassified portion of the basic and applied electronics research program is reviewed.

#### ANTENNA RESEARCH

Almost all electronic systems depend on the emission or reception of electromagnetic energy, and they require an increasing variety of highly specialized antennas, both ground and airborne. The design and development of such antennas is the responsibility of the Electromagnetic Radiation Laboratory, one of the pre-eminent antenna research organizations in the nation.

**HIGH RESOLUTION ANTENNA:** An important part of the Laboratory's recent work has centered on very large aperture antennas. One of its new design proposals, under current development, promises a revolutionary technique for achieving extremely high resolution and gain while avoiding the increasing costs and engineering prob-



A test model of the AFCRL large aperture antenna has been constructed at the AFCRL Strawberry Hill site. Each of the 220 plates of the antenna measures 5 feet square. The plates must be adjusted manually with respect to the feed.

lems associated with the construction of large dish-type reflectors. This new multiple plate technique should provide an effective aperture diameter of 2400 feet, yielding a beamwidth of one minute of arc at L band. By comparison, the 1000-foot Arecibo dish at L Band (discussed below) will have a beamwidth of 3 minutes of arc.

The proposed new antenna will consist of 7000 flat reflecting plates, each about 20 feet square, which when viewed from above will appear as a giant clover-leaf pattern. Located in the center of the array of plates will be an 800-foot tower for the antenna feed. This novel approach should be capable of: (a) providing the greatest coherent aperture and consequently communication or radar range at a minimum loss per square foot of aperture; (b) permitting

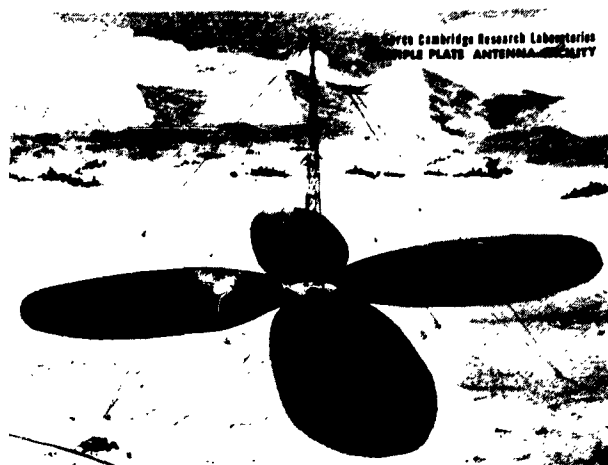
focussing in the near zone (out to an earth radius), thus allowing extreme angular resolution on satellites and missiles near the earth; (c) shaping by computer control the antenna beam patterns for target acquisition at near ranges; and (d) providing rapid beam-scanning on a  $90^\circ$  cone.

During 1961-1962, to check out the above theoretical analysis, construction of a model of the proposed system was begun by AFCRL scientists at Harvard University's field site at Strawberry Hill in Concord, Mass. The model consists of 220 plates and a 100 foot tower, and will be used to assess the contributions to the apparent antenna temperature from spillover, transmission through the plates, and diffraction around the plates. The model, which is the only one of its kind in the United States, is scheduled to be completed during the summer 1962.

#### **ARECIBO IONOSPHERIC OBSERVATORY:**

Another approach to the problem of avoiding enormously costly antenna structures is to use natural geographic features—that is, a huge depression that may approximate a paraboloid or concave spherical shape which can be lined with a reflecting surface. Such a natural sphere-shaped bowl was located among several steep hills in Puerto Rico, a near-perfect site for the construction of the Arecibo Ionospheric Observatory—a 1000-foot fixed radar antenna which will be the largest aperture antenna in the world.

The Arecibo facility is based on original studies of spherical reflector antennas published by AFCRL scientists during the 1950s, and a Cornell University design proposal. Sponsored by the Advanced Research Projects Agency, this \$7,500,000 radar involves erection of instrumentation and equipment (designed by Cornell) in a natural bowl 1500 feet in diameter and 500 feet deep.

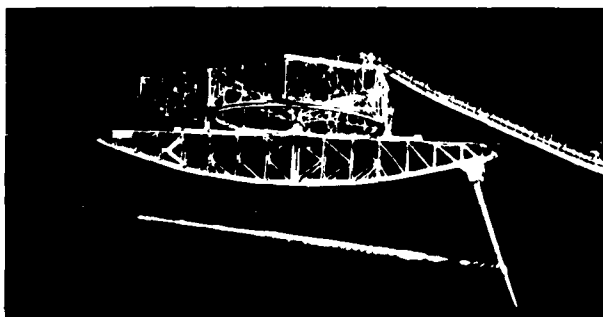


The proposed flat plate antenna will have a clover leaf pattern. Each of the 7000 plates are 20 feet square. The antenna will have an effective aperture of 2400 feet, and theoretically will have a sensitivity 7 or 8 times that of the Arecibo dish.

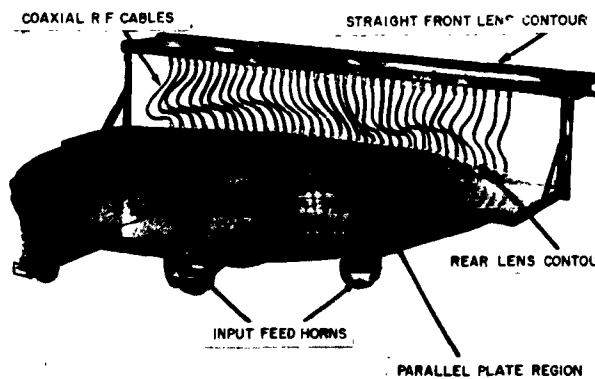


This 96 foot line-source feed constructed for AFCRL under contract for the Arecibo Radio Telescope provides the means for correcting spherical aberrations of the Arecibo dish.

AFCRL responsibilities include serving as manager and technical supervisor during the construction, and providing for the general design of the dish. The spherical design — that is, a segment of the sphere — will permit the antenna to scan over a wider angle (plus or minus  $2^\circ$ ) than the conventional parabola. The special feed mechanism for correcting spherical aberrations grew out of re-



The positioning of the line-source feed with respect to the Arecibo dish is shown in this model. The Arecibo dish is capable of scanning over a 20 degree cone.



This experimental microwave lens antenna was constructed to investigate the lens parameters of the MUBIS antenna systems. The lens has a 3 degree beamwidth at S-band and a scan angle of plus or minus 35 degrees.

search conducted by AFCRL. Movement of this feed permits scanning of the antenna.

The Arecibo telescope operating as a radar will be used for ionospheric investigations and lunar studies. The dish also can serve as a radio telescope for classic radio astronomy studies, observing radio emissions from the planets and stars. At the end of June 1962 most of the basic construction at Arecibo was completed, including the reflector excavation, paved access roads, prime electrical power, water supply, visiting scientists' quarters, and an operations building. The construction of the antenna itself was scheduled to be completed by the end of the year.

**FUTURE GENERATION EARLY WARNING ANTENNA:** Still another AFCRL approach to the problem of avoiding very large and expensive antenna structures, while obtaining greater resolution and performance, is through the synthesis of several independently-evolved antenna techniques into novel arrays. Such a synthesis of techniques is found in the Multiple Beam Interval Scanner (MUBIS) system, which is intended for use in a missile early warning system or for tracking earth satellites.

The MUBIS radar system gives simultaneous height and direction information. In its simplest terms, it is a fixed antenna array generating a multiplicity of separate narrow beams spaced in azimuth over a  $60^\circ$  sector. The system has the ability to scan each separate beam, or the entire family, plus and minus half the angle between adjacent beams, so that all of the azimuth is covered. The MUBIS incorporates a new antenna lens design, consisting of a combination of wide angle microwave unit, cylindrical parabolic reflector, and multiple coaxial organ pipe scanners. Energy collected at the inner face of the lens is constrained to travel through the

coaxial cables to the outer face. By using the cables between faces, elements on the outer face can be spaced in a uniform manner while corresponding elements on the inner face are spaced non - uniformly, thus providing an added degree of freedom in design and construction.

The development of the MUBIS radar system, which was in a prototype configuration in the summer of 1962, was begun several years earlier when Electromagnetic Radiation Lab scientists computed a theoretical design for such an antenna. After comparing the simplicity, flexibility, economy and efficiency of the proposed design with other known techniques having the same or less scan range, they embarked on an experimental feasibility study. An in-house and contractual effort subsequently was successfully carried out in the 1959-1960 period.

**INTERFEROMETRIC TECHNIQUES AND CIRCULAR ARRAYS.** During 1961-1962 laboratory personnel also performed pioneering work on another class of antennas capable of non-linear operations on received or transmitted signals. By employing suitable configurations of radiating elements together with adroit pre-detection, correlation and multiplication, they were able to obtain very high angular resolution with a minimum of radiating equipment. This research consisted of an initial critical analysis of such non-linear antennas, followed by laboratory tests of a new phase-modulated interferometer which demonstrated a capability for unambiguous high-resolution patterns. Since interferometer antennas were extremely large and received partially coherent signals, much of the research was concerned with the distortion of spatial data that was introduced by non-linear operations on incoherent or partially coherent signals. The AFCRL work showed clearly that

non-linear antennas had excellent resolution on incoherent targets but degraded performance on partially coherent targets.

Other investigations pursued during the period involved the basic properties of fixed circular arrays with electronic beam steerability, a concept also originated in AFCRL in the early 1950s. The concept involved amplitude techniques rather than conventional co-phasal techniques to electronically scan the antenna over 360 degrees. By a voltage control



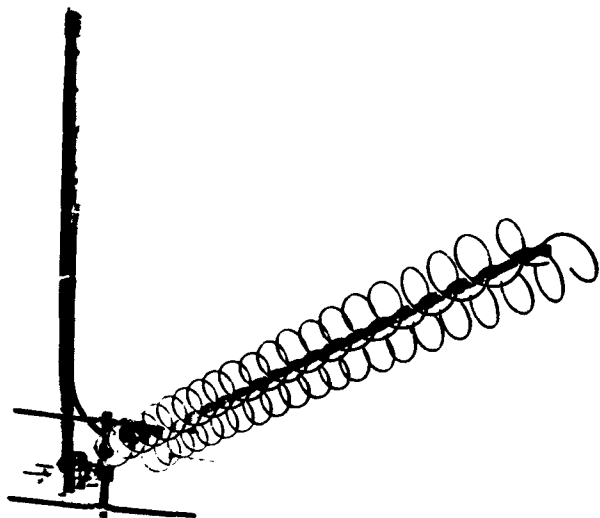
The circular dipole array antenna, based on a concept by an AFCRL scientist, was developed by the University of Tennessee. Amplitude techniques rather than phased array techniques are used to scan the antenna over 360 degrees. The control console for the antenna is shown below.





of signal strength at different points along an array of concentric rings, the beam may be shaped or other desired radiating patterns obtained. Also by properly taking account of mutual coupling, side lobes may be reduced by as much as 30 decibels. Experimental fixed circular array equipment, developed for AFCRL by the University of Tennessee after a four-year research program, was shipped to the Laboratories in the spring of 1962 for further testing and experimental work.

**TRAVELING WAVE ANTENNAS:** Several novel types of endfire radiators also were invented and tested by EM Radiation Laboratory personnel during the period. Several of these fell in the category of "tunable" endfire antennas—a new development which permits operation over a much wider frequency band than heretofore. In one type, two small



The double helix antenna developed at AFCRL is made from a conductive wire wound in such a way that a series of figure eights is described. This antenna is economical to fabricate, transport and erect.

helices—or dielectric rods—are placed parallel to each other; in a second type, they form a small-angle vee. In both, the phase velocity along the radiator-combination is variable, thus producing wideband characteristics. One of the two radiators can always be replaced by a suitably located ground plane. It should be pointed out that the propagation mode on the small helices is not the familiar one (being linear rather than circular polarization).

Two novel antenna types were analyzed by AFCRL scientists, using the surface wave principle but allowing, for the first time, independent control over phase as well as amplitude. The theory showed that accurate beam-shaping was achievable, which was not the case with surface wave antennas.

During the period various contractors contributed extensively to traveling wave antenna work. They produced detailed analyses of the sandwich wire (an in-house invention of several years ago), of the current distribution along surface wave antennas, of antenna sections that are tapered in impedance, and of novel flush feeds that excite surface waves with more than 95% efficiency.

#### **ELECTROMAGNETIC SURFACE WAVES:**

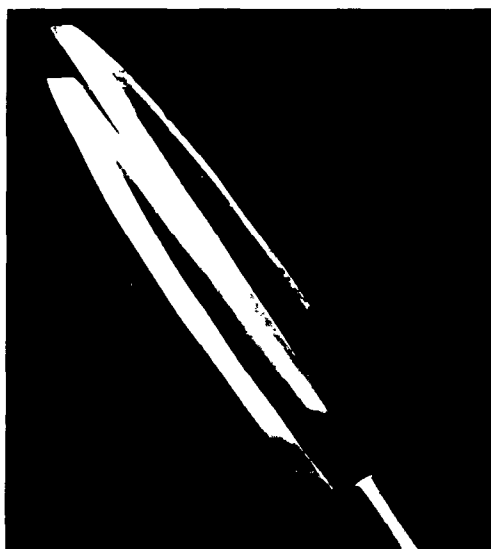
With the help of complex vector or tensor representation for the impedance of surfaces, AFCRL personnel found it possible to treat all types of electromagnetic boundary phenomena from a unified point of view.

Surface and leaky waves that were excited by antennas radiating through a plasma slab (as during re-entry), were analyzed and from their characteristics the radiation pattern of the antenna-plasma combination was deduced. This important relationship was first discovered and worked out by an Air Force contractor, the Polytechnic Institute of Brooklyn. This same contractor also

worked out in detail the field structure of dipoles radiating in an infinite plasma medium, with or without a d.c. magnetic field. Another noteworthy contractor contribution was the theoretical and experimental analysis of "modulated" surfaces, which led to the first correct explanation of Wood's anomalies in optics.

Contractors also contributed to the problem of hardened antennas, by computing the radiation pattern of antennas buried in the soil, and the characteristics of waves propagating in geologically stratified layers.

**THEORETICAL AND EXPERIMENTAL ANTENNA PROGRAM:** As in past years, much of the AFCRL research effort continued to emphasize development of antennas for aircraft, rockets and space vehicles. One special program concentrated on the problem of voltage breakdown of antennas at high altitudes, a



This antenna is called a scissors antenna for obvious reasons. It is fed by a dipole in front of a plane reflector. By adjusting the opening between the "scissors" the antenna can be tuned over a range of frequencies.

subject of much theoretical and laboratory experimental work over a period of several years. During the reporting period the first quantitative measurements of antenna breakdown during actual rocket flight were made by AFCRL scientists. Definite evidence was obtained of voltage breakdown of a slot antenna at 250 Mcps, and in addition the following parameters related to the breakdown were measured: static charge on the vehicle, atmospheric pressure at the nose cone, and heat inputs to the surface of the vehicle at four locations. Additional work on this problem was continuing at the close of the period.

In looking at the problem of achieving maximum profitable use of a given antenna area, AFCRL scientists also considered the related factor of the vehicle, atmospheric pressure at the nose cone, and heat inputs to the surface and degree of coherence of the EM radiation involved. A comprehensive examination of the effects of coherence on the optimum performance of several antenna systems was pursued. In the area of generation, an AFCRL contractor successfully constructed and tested a CW gaseous laser to determine the degree of degradation in coherence when an electromagnetic wave of very high frequency propagated through a turbulent medium.

**PARTIALLY COHERENT ELECTROMAGNETIC WAVES:** During the period AFCRL scientists made several contributions to an understanding of partial coherence phenomena. Effects were calculated of increasing incoherence on the radiation pattern of a circular-aperture antenna, and they found that the gain decreases while the beamwidth increases. The numerical results were of particular interest in gauging the deterioration of antenna performance due to turbidity in the atmosphere. The AFCRL calculation made use of a theorem, discovered and

proved in-house, that related the far field pattern of an antenna to the field distribution and correlation function in its aperture.

Since the coherence of maser and laser outputs depends on the stability of the oscillator, a new approach to the non-linear differential equations governing the population behavior showed that this stability depended on the matching of threshold power to the power needed to maintain the steady state.

At the close of the period the algebraic language used in the theory of partial coherence was being geometrized in a manner analogous to that which proved so fruitful in network analysis. It appeared that both partial polarization and partial coherence could be represented as points in Minkowski space, which provided new light on the relations in which those quantities occur.

**NETWORK THEORY:** Use of higher geometry in solving network problems also was undertaken by AFCRL scientists during the period. The development of a geometric-analytic theory of transforming impedance and power quantities through linear noisy and noiseless networks was continued. Mechanical models of the Minkowski representation of Lorentz space, and the three dimensional non-Euclidean hyperbolic space were fabricated. At the same time, several contractors attempted to extend the theory to the  $n$ -dimensional case, and to obtain stereoscopic representations of three-dimensional network calculations. Using the geometric-analytic network theory mentioned above, some invariant properties in network theory were studied. For example, the Mason unilateral gain and the Schaug-Petersen and Tønning merit factor were investigated by means of the Poincaré model of two-dimensional hyperbolic space. At the close of

the period invariant properties of  $n$ -port linear networks were also being studied by AFCRL contractors.

An important problem in network theory is to synthesize a lumped network when its rational transfer function is known. During 1961-1962 significant contributions to resolving this problem came from Case Institute of Technology and Polytechnic Institute of Brooklyn, both under AFCRL contract.

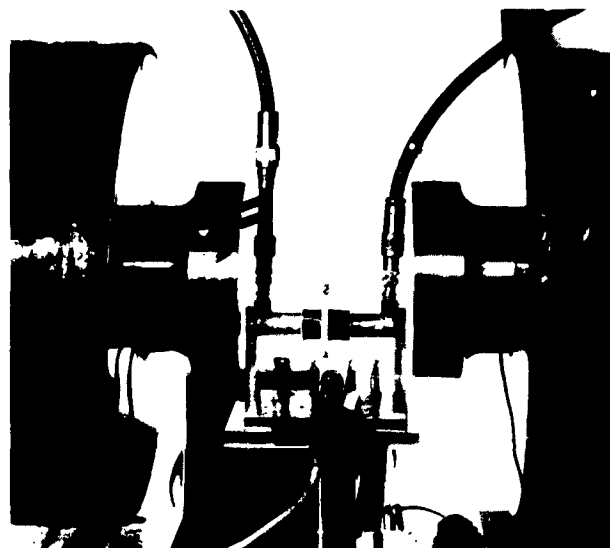
#### **MICROWAVE PHYSICS AND TARGET REFLECTION**

The desire to exploit the special properties of frequencies beyond the UHF region took AFCRL scientists into the millimeter and optical realms of the electromagnetic spectrum — in a search for new components and concepts. The past performance of devices based on the interaction of electromagnetic energy with solid state materials at various frequencies encouraged further study of those materials and of the mechanisms on which device action was based.

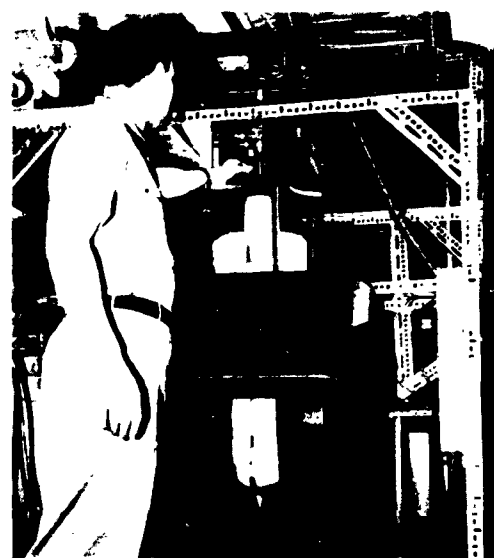
During 1961 studies were completed of the use of ferrimagnetic materials for harmonic and subharmonic generation of microwaves, and of a technique for magnetic pulsing of such materials to produce higher frequency radiation. In the latter work, pulse microwave energy was generated by pulsing, with a high-intensity magnetic field, single-crystal yttrium iron garnet (YIG) from resonance to a higher energy level. The experiments were performed with dual resonant transmission cavities as well as with nonresonant structures. A related in-house study, involved techniques of suppressing spin waves associated with the saturation of ferromagnetic resonance, may lead to a more effective use of ferrite materials in active and passive microwave devices. Several schemes for achieving this were studied, and some experimental data was obtained.

An investigation of the fundamental aspects of relaxation and propagation of spin waves in ferromagnetic materials during the period led to measurements of spin-wave linewidth, exchange-energy constant, and magnetoelastic coupling in single-crystal yttrium iron garnet, using an X-band spin wave spectrometer operable from liquid helium temperature to room temperature. Emphasis was placed on the interaction of spinwaves with phonons of microwave frequency, since the phenomena was extremely useful in determining the characteristics of the material and held promise of being applicable to the generation and control of microwave phonons. A concurrent study was made of other means of generating phonons and of applying the phenomena to probe other structures. Both in-house and at a contractor's facility, phonons were successfully generated via the piezo-electric effect in quartz crystals with considerable improvement in wave uniformity, and phonon propagation characteristics were measured.

In the meantime, millimeter wave component research to find improved techniques for handling 1 to 3 millimeter waves was pursued by another contractor. A theoretical excitation analysis was made for the dielectric image line and the single-conductor wire line, and experiments were conducted showing the use of such structure. Much useful information was obtained on an unconventional means for guiding electromagnetic energy in the 1-3 millimeter region, and various components including harmonic generators, detectors, ferrite devices and circulators, were designed and constructed. A contractor study of ferroelectric phenomena with emphasis on determining the mechanisms of loss at high frequencies also made considerable progress. Notable was the agreement between a quantum



During the reporting period, garnet materials were extensively investigated as a means for generating millimeter waves. A garnet crystal in a microwave line is shown in the experimental magnet.



Microwave phonon properties are being studied in quartz and ferromagnetic garnet crystals. Shown is a setup for generating phonons in quartz at a temperature of 4 degrees K.

mechanical prediction of loss due to the anharmonic crystalline field and impurities, and subsequent experimental separation and verification of the effect.

#### **PROPAGATION RESEARCH**

While the Electromagnetic Radiation Laboratory concentrated its efforts on antennas, microwave physics and studies of the nature of radar returns, other investigations by the Propagation Sciences Laboratory were directed toward learning what happens to a particular signal, what influences affect it, from the time of transmission until it is received. Such influences include various tropospheric and ionospheric phenomena and solar-induced atmospheric disturbances, with one of the conspicuous problems being Arctic propagation disturbances characterized by prolonged periods of absorption.

**HIGH FREQUENCY STUDIES:** During 1961-1962 Propagation Sciences personnel pursued several investigations of high frequency (HF) ionospheric propagation in the Arctic, in an effort to learn more about blackouts in the HF region — events indicating greatly increased absorption as observed during and after intense magnetic storms. For these studies a number of propagation pathways were established between Thule and Concord, Mass., between Fairbanks and Concord, and between Washington and Concord. The work was closely coordinated with related investigations carried out by the Bureau of Standards. AFCRL research resulted in a classification of magnetic storms, which provided a valuable means for predicting magnetic conditions in any succeeding 24 hours period.

In a related program, a method of high frequency communication through Arctic ionospheric disturbances or blackouts was studied under contract.

There was a possibility that on the basis of knowledge of storm growth patterns which Arctic disturbances seemed to follow, and related factors, HF signals could be propagated by alternate paths to get around high absorption in the Arctic regions. Such work was of great importance to Air Force communications networks in the far north.

In the search for a better understanding of the characteristics of the ionosphere over the HF and VHF frequency spectrum, the laboratory employed a new technique involving high frequency (4 to 64 Mcps) radars for the oblique incidence sounding of the ionosphere. Beginning in April 1961 soundings were made between the AFCRL Plum Island site and a receiver located at Palo Alto, California, with propagation at 160 frequencies being accomplished over a 3600 kilometer path. The receiver at Palo Alto remained synchronized with the Plum Island transmitter during the initial three hours of operation, indicating that remotely located sites could be synchronized and simultaneous coherent measurement of forward scatter and backscatter could be made over the path. The technique had a number of advantages, especially for the investigation of transient events such as auroral ionization, ionized meteor trails, and propagation effects caused by geomagnetic storms, sudden ionospheric disturbances, and artificially induced ionospheric phenomena.

Another AFCRL propagation research activity centered on radio waves travelling through various media, including the troposphere, the exospheric magnetosphere as well as the ionosphere. In principle, it was possible to calculate the electromagnetic field including all propagation effects, from Maxwell's equations, provided the refractive indices and their variations in the variable media were known to a sufficient degree.

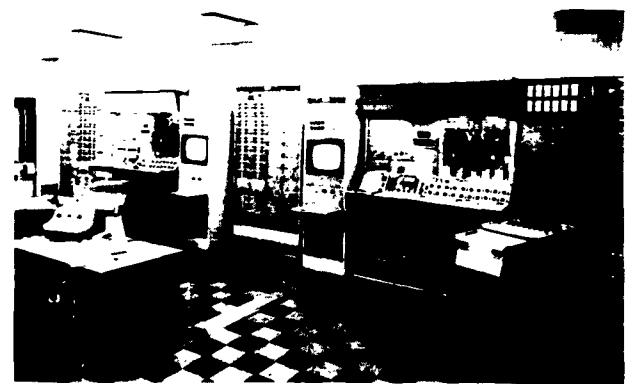
The aim of this research was to gain an understanding, and practical knowledge, of terrestrial and outer space radio propagation phenomena through the inter-relationships of these phenomena with the structures of refractive-index variations.

**PROPAGATION THROUGH OCEANIC DUCTS:** One phase of the in-house work involved the trade-wind belts of the South Atlantic area, where elevated radio ducts often occurred due to the prevalence of super-refracting layers within the first 10,000 feet of air in the troposphere. Within these ducts, radio waves become trapped and can propagate to large distances at small attenuation rates. Thus, for example, an Air Force radar located in Trinidad transmitted and recorded signals reflected from the Atlas Mountains in Africa, a distance of approximately 3900 miles.

During the period February-April 1961 several significant features of the oceanic ducts were verified and demonstrated by radar experiments conducted by AFCRL with the Trinidad transmitter. One was the possibility of a ground base transmitter coupling into the duct. Another was the knowledge that the ducts extended further north than had been suspected, and the fact that the duct continued inland beyond the African coast. In follow-up experiments in January 1962, AFCRL scientists utilized both the Trinidad transmitter and a passive receiver set up at Dakar, Senegal, Africa. Unfortunately no signals were received during the initial checkout of the Dakar equipment, which was blamed partially on high background noise levels and obstructions at the receiver site. Further experiments, in cooperation with the Air Force Missile Test Center and the Dakar authorities, were being planned at the close of the period.

The above experiments were applicable to a new projected AFCRL propagation project, to be performed in the high frequency band between two orbiting satellites moving in the same orbital plane, one transmitting and one receiving. It is believed radio ducting would be encountered, due to the intervening presence of the ionosphere.

**RAY TRACING:** During the period the AFCRL ray-tracing computer facility, the largest analogue computer presently in operation, was used to study radio wave propagation phenomena in non-uniform, non-isotropic media such as the ionosphere — including the geomagnetic field and disturbed ionization conditions. A study was conducted on trapping of HF radio waves in ducts in the exosphere. Rays starting at various angles of elevation from a transmitter on the ground (at 50° north latitude) were propagated via the exosphere to the southern hemisphere. These rays represented the paths followed by radio waves in propagation at 13.7 Mcps. It had been theorized that shells of ionization occurred on occasion in the exosphere, aligned with geomagnetic lines,



The Analog Ray Tracing computer is used by the propagation scientists for tracing the paths of electromagnetic energy in the atmosphere.

and that the electron density in the shells was alternately higher and lower than the ambient electron density by a small percentage. As a result, it appeared these shells had the proper ionization gradients to trap radio waves between 500 kilometers and 10,000 kilometers in altitudes.

During the experiments each ray followed a straight path from the transmitter to a ducting channel, where the ray apparently became trapped and then followed a geomagnetic line to the southern hemisphere. Propagation between ground stations in the northern and southern hemispheres can follow any one of a multitude of ducting paths, depending on where the requisite ionization gradient prevails. These results contradicted the previous theory that exospheric ducting could occur only in the one channel which coincided with the geomagnetic line that intercepted the earth's surface at the transmitter site.

While additional ray calculations were being made, AFCRL scientists also gave some attention to a further development of wave theory. Complex and very tedious, this computational effort on wave theory was needed to supplement actual ray measurements. The latter were considered not sufficiently quantitative in certain respects, such as in determining the rate of decay with height of the signal intensity above and below a radio duct.

#### **LOW AND VERY LOW FREQUENCY PROPAGATION**

Another important area of AFCRL research centered on the very low and extremely low frequency spectral ranges, which have assumed an increasingly useful role in national defense. The VLF and ELF regions constitute an area with potential for long range precision navigation, long range timing signals, and survival communication channels

only slightly affected by disruptive ionospheric conditions, such as might be caused by high altitude nuclear explosions. In view of these possible applications, the Propagation Sciences Laboratory has conducted theoretical and experimental research in the generation, propagation, noise background and receipt in the VLF-ELF regions.

Study of radio wave propagation in and below the VLF (3-30 kcs) previously was handicapped by the lack of a controlled source of radiation pulses. For example, while ionospheric sounders constituted standard equipment at higher frequencies, similar equipment did not exist at VLF and lower frequencies. The basic difficulty involved obtaining transmitting antennas of adequate efficiency. Investigations in the very low frequency and extreme low frequency bands traditionally depended on observations of pulses or "sferics" produced by lightning discharges. A rich source of those frequencies, the natural lightning discharge channel constitutes an enormous antenna, with the transient current in a large flash measuring in tens of thousands of amperes.

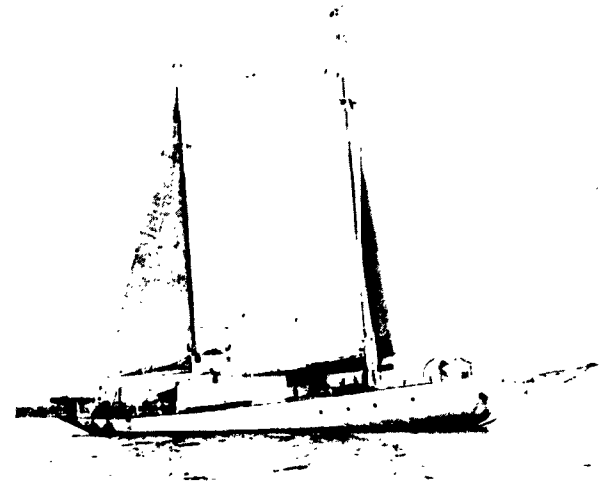
In seeking a relatively inexpensive, controllable and transportable source of very low frequency pulses, AFCRL developed a new technique which produced radiating "artificial sferic" pulses for the first time — using a million volt generator and a 10,000 foot antenna wire. For this experiment, the generator was installed in the research ship, *Azara*, and a technique developed for unreeling and taking up the wire antenna to an altitude of 3,000 feet with a small helicopter. During the initial full scale tests (July 1959), after a high voltage bank of condensers was discharged into the lower terminal of the wire, the resulting signals were received at AFCRL's radio interferometer

facility at Mount Wachusetts, 100 kilometers away.

Since that time an extended set of transmissions was made and received from the ship located in Chesapeake Bay over a distance of 600 kilometers. Arrival-time differences were measured for a total of 101 individual pulses transmitted on four successive days. Analysis of the data indicated that the artificial spheric technique could be used to calibrate the hyperbolic direction finder to an accuracy (probable error) of about  $0.06^\circ$  or better. In the summer of 1961 the net demonstrated its ability to receive the artificial pulses from an even greater distance. This time the ship was located off the coast of Florida, a distance of 1600 kilometers and again the pulses were easily detected.

In an effort to obtain even more power and lower frequencies, AFCRL has planned to use even longer antennas and higher voltages, with the wires to be carried to much greater heights (30,000 feet) by small ship-launched rockets. Although only a limited transmitting capability was expected using this technique, it was believed it would be adequate for research purposes and possibly for sending a brief message. At the end of the period development work on the technique was proceeding.

An extension of the rocket-wire project also called for attempting to inject the wires into thunderclouds to induce lightning to strike. If successful, the lightning discharge channel would follow the wire down to the ship, and the currents and electrical properties of the discharge could be measured. Since the *Azara* has a heavy bronze hull, it was expected it could sustain a "direct hit" with little damage. Ultimately, the scientists hoped to develop methods of keeping the discharge channel alive and "captive" for a short period of time,



The yacht *Azara* was used by an AFCRL contractor in connection with an experiment designed to draw lightning from the thunderheads down a fine wire. The wire was carried into the thunderhead by small rockets launched from the *Azara*.

during which the ionized channel might serve as an antenna.

**LOCATING SPHERICS:** During the period the Mount Wachusetts radio interferometer facility also was used to test the accuracy of direction finding with natural and artificial pulses, as well as amplitude and phase stability of VLF propagation modes during day and night, sunset and sunrise, solar flares and auroral activity. With Wachusetts serving as the master station, three outlying stations were employed in direction finding at Hogback, Vt., Jerimoth, R. I., and Derry, N. H. These unmanned outlying stations had two functions: (a) to receive VLF signals on a vertical antenna; and (b) to relay them continuously over a microwave link of known time delay to the Wachusetts station, where they were displayed on oscilloscopes and photographed.



As one phase of the direction-finding effort, for several years AFCRL ran experiments to determine the ability of the net to locate sferics originating in Western Europe. In the summer of 1959 and again during the spring and summer of 1961, a series of coordinated trans-Atlantic experiments was made and sferics were observed by the New England net and a similar sferics net in Great Britain. The British Meteorological Office furnished the geographical coordinates of the lightning stroke, so that measurements of position could be compared. Results of 150 sferics recorded during 1959 showed an average absolute deviation from the mean of 31 nautical miles. These runs were conducted, however, with the propagation paths entirely in daylight. During the 1961 experiments efforts were made to determine if any possible errors were introduced by diurnal variations, such as the effects on very low frequency propagation of a sunrise or sunset interface on the path. Based on a preliminary evaluation of these experiments, it appeared there was no marked diurnal effect on system accuracy.

The possibility that a greater error might be introduced when the propagation paths from the source to two outlying stations fell almost parallel with the sunrise line also was investigated, using transmissions from a station in Panama in a nearly North-South direction. The phase of received VLF signals was known to exhibit diurnal variations, with the dominant feature being a phase advance for daylight conditions and a lag for nighttime. It was anticipated that, with two nearly equal propagation paths, the relative phase would be about the same before and after the passage of the day-night interface, with a transient perturbation between. The results of the experiments, conducted in October 1961, were as ex-

pected, the phase transient starting as the first rays of the sun reached an altitude of 80 kilometers above Derry, N. H. The maximum phase shift occurred approximately seven minutes later and was about  $30^\circ$  at a time difference of about 5 microseconds. This phase shift would cause an error in direction finding to the New England net of  $0.7^\circ$ .

In seeking to measure the intensity of sferic noise signals, one of the problems facing the researchers was to separate the received signals and catalogue them in terms of source strengths. Naturally a weak sferic signal originating near the receiving antenna would produce a larger output voltage than a very powerful source at a much greater distance. To resolve this problem and to develop the needed classification, two AFCRL stations were set up for receiving and direction finding, one located at Hanscom Field and the other at Westover AFB, which provided a baseline of 66 miles. These stations were run almost continuously 24 hours a day, with a recording threshold such that in the 30,000 square mile area of New England being monitored, only the more powerfully radiating VLF lightning strokes would trigger the oscilloscopic recording apparatus at both stations. Weaker sources were capable of triggering one or the other of the stations, but not both.

The analysis procedure consisted of superimposing the photographic film records from the two stations, making use of timing marks, and then reading the data manually. Each individual source had its position plotted, waveform copied, and was classified as to source strength, initial polarity, extremely low frequency content, presence or absence of a higher frequency burst, and delay in the abnormal component of the sky-wave relative to the ground wave. The analysis work proceeded on a scheduled basis during the period. Extremely

powerful sources of as much as 7 S-units were observed (one S-unit equaling 1000 v/m at one mile). Contrary to expectations, the scientists found that the "very powerful" category of lightning strokes contained specimens of both positive and negative polarities.

Among the other interesting in-house and contractual studies pursued during the period was a program of recording upper atmosphere noise emissions, using a number of receivers sited in New England, Spain, Italy and Israel. The origin of the noise emissions was something of a mystery, with one favored explanation being that they were Cerenkov radiations produced by high speed particles travelling faster than the electromagnetic velocity appropriate to the medium. Noises from cosmic and solar sources also were monitored by radiometer receivers emplaced in various locations in Europe, the Caribbean and North and South America. Data collected were to be forwarded to AFCRL for analysis.

Besides the above activities, AFCRL scientists also studied the possibility of artificially modifying propagation media through various chemical or physical means, and the coherent propagation of electromagnetic energy at frequencies below one kilocycle.

#### COMMUNICATIONS RESEARCH

In the area of communications research, the Communication Sciences Laboratory of AFCRL pursued studies that encompassed microwave and optical devices, information processing equipment and advanced circuit complexes, and new long range communications techniques including transmission and reception of signals beneath the earth's surface. The search for new devices and techniques for full exploitation of the microwave spectrum emphasized the region with wavelengths shorter than 3 centimeters.

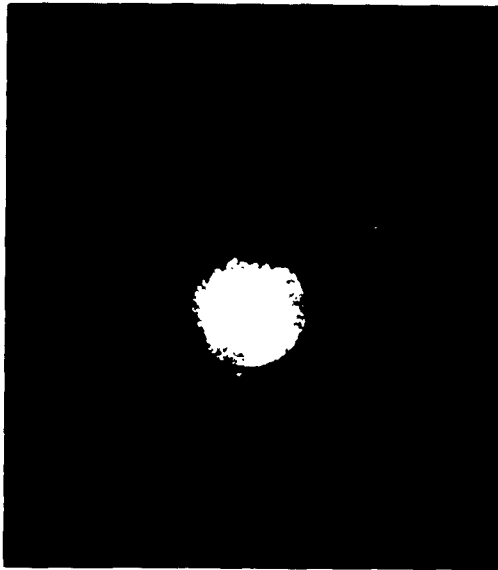


AFCRL's laser research is basically concerned with the evaluation of ruby crystals for lasers. Here a ruby is being inserted into the laser cavity.

**LASER RESEARCH:** One of the Laboratory's most interesting areas of communications device research, aimed at exploiting the optical regions of the spectrum, centered on the laser. Within months after Hughes Laboratories announced the first successful laser operation, the Communication Sciences Laboratory began to assemble equipment and in January 1961 placed its own ruby laser oscillator into operation.

The AFCRL program concentrated on gaining a detailed understanding of the optical fine structure of the host lattice and active agent; such factors as crystal imperfections and impurities. A secondary emphasis was on external influences such as pump characteristics and applied electric, magnetic and mechanical fields.

Based on their early experiments with the ruby crystal, one of the conclusions of AFCRL scientists was that the highly varied intensity patterns on the faces of oscillating laser materials could not be



An efficient laser is one in which the entire front end of the ruby crystal is illuminated evenly. This photograph shows the far field radiation pattern of a laser rod fired 35 percent over threshold.

attributed solely, or even largely, to non-uniformity in reflecting coating or flatness and alignment of the faces. This result corrected theories of laser action prevalent at the time. Work proceeded to the examination of far-field patterns and their relation to various laser parameters. A noteworthy finding was that the same relationship holds between fringe width and optical quality of the crystal as would be predicted for a passive etalon. These patterns were considered at AFCRL to be basically Fabry-Perot fringes, though the exact mechanism by which they arise was not yet clear. The topic was still under active investigation at AFCRL and by a few other groups.

At the close of the period two laser experiments were in progress. One involved examining the time variation of individual frequencies of the laser output. This was being done by several

groups. The experiment at AFCRL, however, employs a different technique, allowing observation during an entire flash (or indeed longer, should a steady-state source become available) and very close to threshold. It also was easily adaptable to infrared frequencies. The second experiment was concerned with transient polarization effects in the output of  $0^\circ$  oriented ruby crystals. Such effects were first postulated on the basis of theoretical considerations, suggested in part by a short-exposure near-field studies of  $0^\circ$  crystals. Their existence has now been revealed, and experiments were continuing to further check the underlying theory. (If the theory is correct, it suggests several possible reasons why some previous experimenters were led to conclude that polarization effects did not exist.) This whole investigation may in the end throw considerable light on mode phenomena in the ruby laser.

Another AFCRL undertaking of a completely different sort involved an attempt to devise a gaseous laser based on stimulated radiative recombination. This notion was conceived in-house, and initial theoretical work done on it. Since then it has been pursued in close collaboration with a contractor. Rather special techniques for plasma production are required, and experimental difficulties loom large; however, since a laser of this type would have unique properties, the work is considered well worth pursuing.

While great interest centered on the still fledgling field of lasers AFCRL scientists also investigated other areas in a search for new devices for information processing for communications. The emphasis here was on designs compatible with micromodule, thin film and other small-space and power techniques. The related work centered on studies of circuit complexes with promising functional characteristics.



The axial modes of the ruby laser that have been separated by an interferometer are shown here.

**MICROWAVE DEVICES RESEARCH:** The central aim of this work is to devise oscillators and amplifiers with such properties as extreme tunability or bandwidth, noteworthy operating frequency and comparatively high power. A collaborative effort, in-house and contractor, it seeks to explore theoretically and experimentally — in plasmas — the feasibility of obtaining amplification of electro-magnetic signals through the mechanisms of cyclotron radiation and bremsstrahlung. During the period in-house theoretical work in this area provided the first adequate understanding of predicted effects of this type, facilitating comparison with more conventional amplification mechanisms. A complementary, purely contractual program also was pursued, exploring new types of effects in solids.

**MILLIMETER WAVE COMMUNICATIONS:** In 1961 the Communication Sciences Laboratory also initiated a research program in super high frequency (SHF) and millimeter wave communications.

The purpose was to provide a statistical description of the impact of the atmospheric environment on communications links operating at frequencies above the X-band, and then to devise techniques to exploit the capabilities of that part of the spectrum.

AFCRL scientists had found the existing design criteria for SHF links operating in or through the atmosphere were typically based on limited observation of the "steady-state" nature of the transmission and ground environments. Operating frequencies, antennas, modulation and required power had been determined in the past without benefit of sufficient knowledge of the statistical effects of the atmosphere and local ground conditions.

As part of this effort, during the latter half of 1961 a new millimeter wave radiometer system was completed and tested, and airborne X-band noise environment tests were begun. The latter equipment consisted of a Dicke radiometer and a 12-inch parabolic antenna mounted on a KC-135 aircraft in back of a hole cut in the starboard side, forward of the wing. The radiometer operated on a frequency of 8 Kmc, had a 10 Mcps bandwidth and was capable of relative measurements to an accuracy of  $2^\circ$  Kelvin. The antenna had a  $10^\circ$  beamwidth and could be swept in elevation from  $-5^\circ$  to plus  $20^\circ$  relative to the aircraft horizon.

The flight tests were conducted between August and December 1961, at various locations within the western hemisphere, and they demonstrated that the operation of the aircraft had no measurable effect on the noise temperature observed. Variations of speed and power setting did not alter the observed readings, and no interference was noted from any of the aircraft radar, radio or other electric equipment. The deduced external noise temperature as measured

for high elevation angles ( $50^\circ$  to  $70^\circ$  above the horizon) were in the order of a few degrees Kelvin.

The experiments clearly demonstrated the feasibility of operating a low-noise X-band receiver in a high speed jet aircraft. AFCRL personnel further concluded that antenna location and beam pattern were of prime importance as system performance could be limited by the amount of radiation from the Earth included in the side lobes.

#### **SUB-STRATA AND SCATTER COMMUNICATIONS**

The requirement to devise long range intrusion-resistant communications capable of surviving a nuclear blast also became a part of the AFCRL mission. One unique approach to the problem was a study of transmission of low frequency radio waves through the earth via sedimentary layers and that portion of the crust known as the granitic basement complex. Although tests made by other groups had produced encouraging results in this area, new problems — such as the detailed electrical characteristics of the transmission layers — remained to be investigated.

AFCRL's deep strata communication program was initiated during 1961 with contractual support. The early experiments involved studies of the electrical properties of the earth's various layers through electromagnetic measurements. Noise backgrounds were surveyed at low frequencies above and below the shielding overburden, and potential paths were surveyed on the basis of available geological literature. Working as a team, in-house and contractor personnel performed theoretical studies on path loss, antenna design and antenna-to-medium coupling during deep strata communications. A frequency measurement program was conducted which gave a general picture of transmission param-

eters. Impedance measurements were made of several types of antennas imbedded in the rock medium, and measurements on proposed antenna configurations were performed in granite quarries and existing wells in New Hampshire.

In order to examine the significance of telluric currents in communications, electrodes and a measuring and recording system were fabricated by an AFCRL contractor and initial measurements were made. The experimental equipment was devised to measure signals to the 0.01 cps to LF region, using both a long wire antenna and telluric potential electrodes. The purpose was to obtain a thorough picture of the natural and man-made signals over that frequency range and knowledge of the relative effectiveness of the input devices (long wire antenna or electrodes) as a function of frequency.

Plans called for drilling holes through several hundred feet of shielding overburden to bed rock in the Cape Cod area, and installing the antenna with the completely shielded transmitting and receiving terminals. In the full-scale test program, transmissions were to be conducted to determine path attenuation, antenna characteristics and the electrical constants associated with the rock medium.

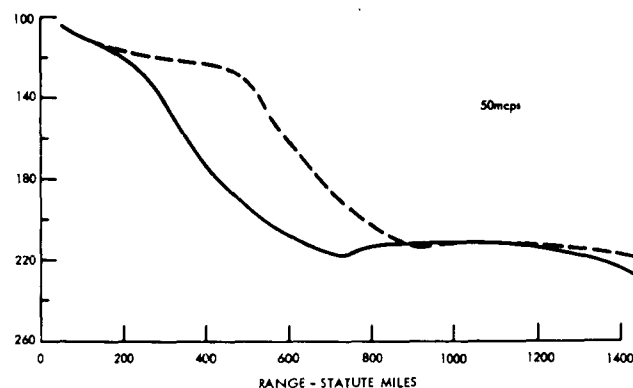
**AIR-GROUND SCATTER COMMUNICATIONS:** During the period AFCRL successfully concluded a four year research effort, demonstrating the feasibility of long range air-ground VHF ionospheric scatter communications. It had been undertaken to satisfy an Air Force need for reliable communications especially across the "auroral belt" where conventional high frequency propagation often became seriously disrupted. The VHF ionospheric scatter communications effort appeared to hold promise of a

reliable, single frequency circuit with ranges up to about 1400 statute miles. All research connected with the program was completed in 1961.

The initial phase of work involved test flights conducted during the years 1957-1958 in conjunction with Lincoln Laboratory to determine the distance dependence of ionospheric scatter field strength. After sufficient data were accumulated, a prototype two-way circuit was designed and full-scale experimental flights were conducted from the fall of 1959 through the spring of 1961. Both the air-ground and ground-air channels operated on a frequency of 49.62 Mcps, employed diversity techniques to improve the error rate and had relative broad beam antennas for both transmitting and receiving. Modulation used was FSK with a frequency spacing of 6 Kc and a baud rate equivalent to that of a 60 WPM synchronous teletype channel. Baud synchronous detection was used to obtain maximum sensitivity. The method of diversity combination employed was post detection maximum signal selection.

The flight tests were conducted using a KC-135 type aircraft over a path extending north from Bedford, to a point 1500 statute miles distant. This path lay directly across the region of maximum auroral activity. During each flight recordings of signal strength and baud error rate were made. Ground-air tests were conducted at various times of the day to determine the diurnal variation, if any, in system performance. Due to location interference and noise encountered at the ground receiver site, air-ground tests were made only during the hours after 2200 and before sunrise. All flights were conducted at normal KC-135 speeds and at altitudes from 33,000 to 37,000 feet.

No disruption of the received signal was noted during periods of auroral



The median path loss of a 50 Mcps signal transmitted to an aircraft flying at 40,000 feet is shown. By ground to air scatter propagation techniques, reception was obtained out to 1400 miles and beyond.

activity. In fact, periods of strong aurora were almost always accompanied by signal enhancement many decibels above the expected levels. During every flight signals were recorded and identified to at least 1400 statute miles. The results of the above program clearly demonstrated the feasibility of an air-ground communications circuit utilizing ionospheric scatter propagation. Distances up to 1400 statute miles appeared realizable with a proper choice of system parameters. The AFCRL system operated to distances of about 1200 miles.

#### DETECTION IN THE AEROSPACE ENVIRONMENT

One of the keys to providing timely detection and early warning information on the flight of ICBMs and satellites involves interaction in the aerospace environment of electromagnetic energy emitted or disturbed by those man-made objects. While many groups at AFCRL contribute to various aspects of this problem, the Detection Physics Laboratory in particular has been engaged in research on advanced concepts and tech-

niques for detection, location, and identification of aerospace targets—including rockets, missiles, satellites, explosions and other man-made events. Of necessity, many of the specific details of significant results have been omitted from this unclassified report.

Fundamental to any consideration of long range detection and sensing is the need for information on the nature and characteristics of the interactions between these aerospace targets and their environment—e.g., emissions of energy, or disturbances to a flow of energy or a field. Scientists of the Detection Physics Laboratory during 1961-1962 devoted considerable efforts to studies of the electrophysical characteristics of artificially induced disturbances and electromagnetic interactions in the aerospace environment. Investigations of these disturbances and related electromagnetic phenomena were pursued through an integrated program of theoretical studies, controlled laboratory experiments, and field measurements. Some of the probing techniques used in these experiments yielded valuable preliminary information on possible operational sensing concepts.

**IONOSPHERIC DISTURBANCES:** Since many targets of interest occur in the ionosphere and above, a significant portion of the Laboratory's work centered on artificially induced disturbances in that region, and their effects on electromagnetic waves propagating through the medium. It was recognized that the nature of these interactions and resulting disturbances was affected in large measure by the special characteristics of the ionosphere itself, a low density plasma under the influence of the geomagnetic field.

Based on hydromagnetic theory, the scientists postulated that man-made activities in this environment would

induce travelling disturbances or waves in the ionosphere. A number of field experiments were performed to investigate this hypothesis. Many rocket launchings were monitored and probed at a variety of radio frequencies from several ground locations at various ranges and aspect angles. Similar probings were made during certain satellite passages. Since any disturbances in the ionosphere in turn induced fluctuations in radio waves propagating through the medium, AFCRL scientists were able to search for and measure the characteristics of the disturbances themselves.

In another experiment, the Laboratory installed three mutually orthogonal 10,000 turn induction loops at a remote section of Fort Devens. These magnetometer measurements were recorded continuously and correlated with the passage of known orbital vehicles, during which times increases in intensity were noted. While these results were encouraging, this field experiment was severely hampered by low frequency noise, and at the close of the period the test was suspended pending the availability of more precise data from controlled laboratory investigation. (A more complete discussion of Detection Physics Laboratory work in theoretical analyses and controlled laboratory experiments on the generation, propagation, decay, and inter-modulation of certain types of hydromagnetic waves will be found in Chapter VIII.)

**ENHANCED RADAR CROSS-SECTIONS:** AFCRL scientists also were interested in the ion sheath phenomena, and its associated build-up of electron density which occurs in the vicinity of orbiting vehicles.\* During the reporting period theoretical studies were initiated on the mechanisms involved in this build-up,

\* See also Chapter VIII.

and analytical methods were developed to predict echo areas for arbitrarily shaped bodies. Experimental evaluations of enhanced cross-sections were investigated by monitoring signals transmitted from artificial satellites. Measurements of Faraday rotation and doppler shift were used by a team of university and laboratory scientists to obtain indications of the density, extent, and duration of ionization produced by the satellite's motion through the ionosphere, and to derive estimates of cross-sections enhancement.

The hot exhaust gases from a burning rocket expand to form an ionized trail which adds to, or enhances, the cross-section of the vehicle. During the 1961-1962 period the characteristics of this enhanced trail were investigated both theoretically and experimentally by Detection Physics Laboratory scientists. The theoretical work included the approximate size of the rocket trail; i.e., the approximate size of the boundary of that part of which the electron density was greater than the critical value at the given frequency.

A related program—to determine the ionization contours of rocket exhausts by means of controlled experiments—was completed during 1962. Burning engines, from one pound to 50,000 pounds thrust, were measured in a contractor's facility at altitudes from sea level to 75 kilometers. Both solid propellants and liquid propellants were used. From these measurements, the scientists were able to construct ionization contour maps of regions within the exhaust plume and outside the luminous zone. Microwave interferometers were employed to measure electron number densities and served as a basis for calculating temperature distributions. As part of this work, a new probe was developed which measures the linear conductivity directly and eliminates the

normal log response characteristic of most probes.

Field tests also were conducted on actual rocket launchings at various radio frequencies, and brought in data on the size, shape, decay and aspect sensitivity of the trail as a function of altitude, time, frequency, etc.

On the basis of these investigations, sufficient information became available to permit assessment of various possible electromagnetic sensing techniques for detection of the enhanced targets.

**ENGINE RADIATIONS:** A rocket engine, during the burning phase, emits various kinds of electromagnetic radiations, with perhaps the most important portions of these radiations occurring in the infrared part of the spectrum.\* However,

\* AFCRL's extensive work in infrared research is reported in Chapter VI.



Infrared devices looking at the flame of a missile can tell a great deal of the composition of the combustion materials of the missile, and something of the design of the missile itself.



there are radiations in other portions of the electromagnetic spectrum which might be of considerable importance for long range detection and sensing, if they are of sufficient magnitude. During 1961-1962 scientists of the Detection Physics Laboratory investigated such radiations, with particular emphasis on the mechanisms responsible for their generation.

One possible mechanism studied by the scientists is nuclear magnetic resonance. Although this phenomenon has been demonstrated in solids, little consideration has been given to thermal generation of the resonance as a gas undergoes rapid temperature changes. It became apparent that existing theoretical models for nuclear magnetic radiations were inadequate for high temperature dynamic systems. Estimates of the order of magnitude of possible radiations were made, but the theory would not support detailed calculations for these systems. To obtain experimental data, and in order to take advantage of available high temperature gaseous systems, the scientists of the Detection Physics Laboratory conducted experiments using jet engines at Hanscom Field. At the close of this reporting period, work was underway to extend these measurements to other high temperature gases for future verification and to enable projection of a more adequate theoretical model.

Because of the long range propagation characteristics of very low frequency EM waves, particular attention was given by Laboratory scientists to radiations in this frequency band from burning rocket engines. Through a series of carefully controlled measurements, the scientists were able to determine the magnitude and detection range of these radiations.

Other in-house studies were made of electromagnetic radiations from non-

conventional power plants. A plasma engine was simulated in the Laboratory to study electromagnetic radiations from this type of engine. A 60,000 volt power supply was used to energize a 14,500 joule capacitor bank. When the capacitor bank was discharged by a triggered spark gap, a peak current of 80,000 amperes was delivered in a 30 microsecond pulse. The plasma was pre-ionized by a 50,000 volt induction coil which is sufficient to seed the chamber, allow integration, enhancement, and develop thrust as the high current is passed. The Laboratory also pursued theoretical investigation on the radiative properties of these exhaust structures when moving at high speed in the space environment.

**OVER-THE-HORIZON DETECTION TECHNIQUES:** Based on investigations such as those discussed in previous sections, Detection Physics Laboratory scientists during the period identified several phenomena and electromagnetic sensing techniques having a high potential for detecting certain types of enemy activities from beyond line-of-sight. As a result of successful field experiments, an expedited program — Project CAMEBRIDGE — was initiated early in 1962 to determine various scientific and technical parameters of possible operational configurations.

Extensive networks of field sites, both in the United States and overseas, are being established covering large geographical areas. One site is operated by Laboratory personnel, with most of the others to be operated under contract. Measurements at the field sites will be recorded on magnetic tapes to be sent to the Evaluation Center at the Detection Physics Laboratory for reduction and analysis. From such data, the scientists will be able to derive such information as detection reliability, false alarm

rates, interference, coverage, etc., and to evaluate the relative efficiency of different techniques.

At the close of the period several of the CAME BRIDGE field sites were in operation and limited data was being made available. As more sites become operational and the data flow increases, more reliable determination of some of the parameters which depend on statistical analysis will be accomplished.

On the basis of existing knowledge of generating mechanisms, the scientists also sought to predict significant target signal parameters and signature characteristics. This work was supplemented by detailed examination of frequency-time plots and parametric analysis of actual signal fluctuations obtained from the field experimental data. The tedious job of data processing and detailed analysis of signatures was expected to be greatly alleviated during 1962 when a new AFCRL dynamic digital data processor became available. In the meantime, the Detection Physics Laboratory, on the basis of gross analyses of possible signatures, accomplished work on the design and evaluation of simple processing circuits for possible on-line utilization. The results of this essentially empirical work were highly promising and left little doubt that suitable real-time processors could be made available as signature characteristics were more precisely defined.



The pod released from the Atlas missile contained a standing-wave impedance probe and a sweep frequency impedance probe for the measurement of the electron density in the missile trail.

**Q** During 1961-1962 three in-house groups were actively engaged in research into the physical and chemical properties of the upper atmosphere and near-space, including infrared transmission, and the nature of the ionosphere, magnetic fields and cosmic radiation phenomena. This research — conducted by the Space Physics Laboratory, Optical Physics Laboratory and Ionospheric Physics Laboratory — was aimed at uncovering new knowledge of those regions where future Air Force space vehicles will operate. Some of the research was related to other in-house studies in the electromagnetic wave sciences and meteorology discussed in earlier chapters. As was the case with those related programs, much of the new data were accumulated through the use of radar and radio astronomy techniques, and ground and airborne equipment, but particularly through the use of suitable sensing devices placed aboard balloons, rockets and earth satellites. During the period AFCRL sensors flew on the backs of several dozen Air Force ICBMs, on scores of vertical rockets and on polar orbiting satellites. Future plans call for the instrumenting of a new and important vehicle — the X-15 rocket research plane — to carry AFCRL sampling devices into the higher regions.

The AFCRL studies in aerospace physics were highlighted by a number of important achievements, including: creation of artificial meteors which produced data relating luminosity as a function of their mass; significant advances in infrared technology; accumulation of new data on radiations in the near-earth region and additional

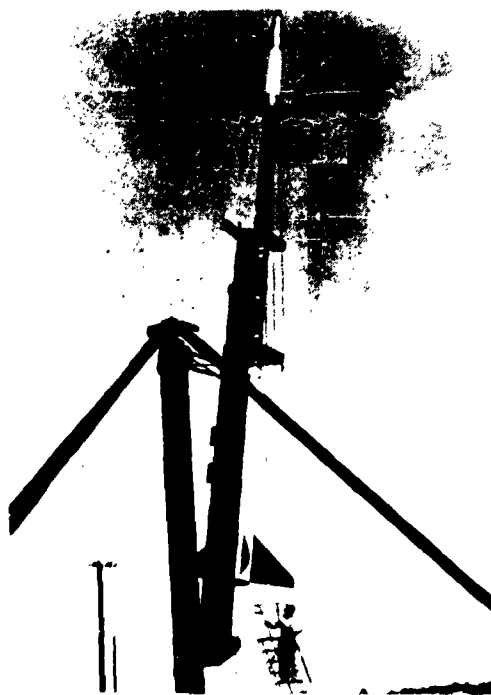
information on ionospheric characteristics and auroral phenomena. The story of these and other AFCRL advances will be covered in detail in this chapter.

#### UPPER ATMOSPHERIC PROPERTIES

One of the areas of particular interest to scientists of the Space Physics Laboratory, whose work included spectroscopic and nuclear studies, upper atmospheric composition and chemical physics, has centered on the presence of extra-terrestrial particles in the aerospace environment. Such meteoritic particles, if of a sufficient size, might constitute a hazard to Air Force satellites, space vehicles and space probes. On a lesser scale, their interaction with atmospheric gases may have a bearing on Air Force communications and detection operations.

**ARTIFICIAL METEORS:** As one phase of the above research, in April 1961 and May 1962 AFCRL scientists successfully created the first artificial meteors in history. The main purpose of this AFCRL experiment was to determine such parameters as luminous efficiency and ionization efficiency of entering bodies of meteorite velocities. The experiments involved launches of multi-stage rockets from NASA's Wallops Island facility.

During the first meteorite launch of 11 April 1961 the fourth, fifth, and sixth stages fired on the descent from an altitude of 195 kilometers, with a seventh stage further accelerating a steel pellet to a speed of 10 kilometers per second. As it descended to an altitude of 70 kilometers, the pellet began to glow and then to burn—a man-made meteor. The light from the meteor, a thin bright trail in the sky over Virginia and North Carolina, was recorded by Baker Super Schmidt cameras, and provided data on luminosity of a particle of known size and mass. Measurements also were



This seven-stage trailblazer rocket was used to carry a three-quarter inch steel disk to an altitude of about 200 miles. Fired downward into the atmosphere at a speed of about 12 kilometers per second, the pellet became an artificial meteor visible for many miles along the Virginia and North Carolina coasts. The size of the steel disk is indicated in the photograph below.

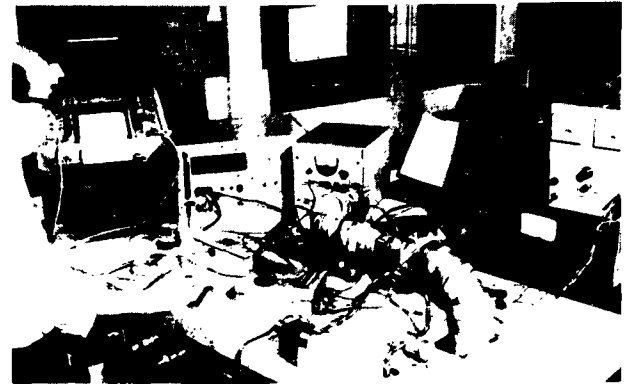


made by radar. The second launching, on 6 May 1962, produced the highest re-entry speed ever recorded for a man-made object. The steel pellet travelled approximately 12 kilometers per second. At the close of the period analysis of the data was continuing.

#### **SAMPLING THE UPPER ATMOSPHERE:**

In pursuing research into the composition of the upper atmosphere, Space Physics Laboratory scientists during the period gave special attention to efforts to improve existing instruments. In the case of mass spectrometers, difficulties had been encountered because of lack of data relating the measurements inside the instrument to ambient conditions outside. To do this adequately required a knowledge of the various processes occurring while a stream of atoms and molecules was entering the measuring instrument. Whereupon, a thorough laboratory calibration program was begun using synthetic atmospheres as well as dynamic calibration in a wind tunnel to clarify some of the processes. A mass spectrometer was developed for measuring composition from 50 to 90 kilometers, a difficult region to make measurements because of the high pressures involved.

Subsequently, in August 1961, two time-of-flight mass spectrometer systems were successfully flown on balloons from Faribault, Minnesota, and continuously sampled the atmosphere from ground level to approximately 100,000 feet. The systems were unique in that a servo-controlled leak mechanism was used to maintain the pressure inside the spectrometers at about  $10^{-5}$  mm to within plus or minus 5 percent over an ambient pressure range of 750 mm to 10 mm. A flushing system was used to reduce the long periods needed for the diffusion process to occur in the sampling tube before a true sample of the atmosphere



A time-of-flight mass spectrometer to be flown on a satellite is being calibrated for its relative response to various gases such as nitrogen, argon, oxygen, carbon dioxide and helium.

could be obtained on the high-pressure side of the leak. Response time for true samples was on the order of a few seconds instead of hours.

During the August flights the mass spectrometers were housed in pressure tight gondolas with three-foot intake tubes to eliminate balloon and gondola perturbations. Helium, oxygen and nitrogen were among the elements sampled by a commutator moving at a rate of one segment per second and telemetered by an FM-AM system. Data were obtained on one of the flights during both the ascent and descent, and on a second flight during ascent only. Three other balloon flights were unsuccessful, although the mass spectrometer systems performed well in all instances. The failures were attributed to antenna and transmitter problems and balloon difficulties.

In conducting related research on electrically charged particles (ions, electrons) at higher elevations, Space Physics Laboratory scientists also developed an electrostatic analyzer experiment to measure those properties. This AFCRL device is capable of measuring

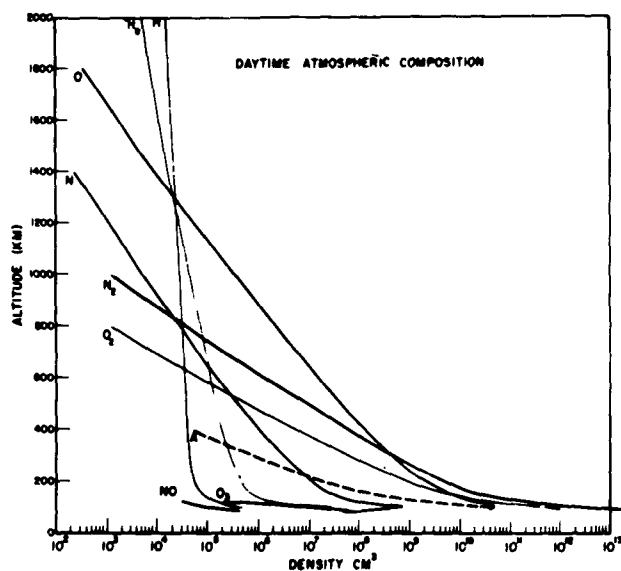
charged particles of a given sign from  $10$  to  $10^7$  per cubic centimeter and energies up to 1000 electron volts.

On 12 April 1961 one of these devices was successfully flown aboard a Blue Scout rocket fired from Cape Canaveral. A maximum density of  $3 \times 10^5$  ions/cm<sup>3</sup> was observed at 325 kilometers, while at a peak altitude of 2000 kilometers a minimum density was recorded of  $2 \times 10^4$  ions/cm<sup>3</sup>. The computed scale height at the peak in the F<sub>2</sub> region of the ionosphere was 90 kilometers, with the scale height increasing above this level. Assuming an average mass of 18 atomic mass units, the ion temperature in this region was 1700° Kelvin. One of the surprising results of this Blue Scout flight was the measurement of a lower scale height for ions than had been previously supposed. This cast considerable doubt on the hypothesis proposed

by several investigators, of an oxygen-helium mixture in diffusive equilibrium. The same type of experiment was flown from Cape Canaveral in follow-up launchings on 22 November and 19 December 1961, and good data were received for analysis.

Another important flight of two spherical electrostatic analyzers occurred on 13 October 1961 aboard an Air Force satellite fired into polar orbit from Vandenberg AFB. It measured the concentration and energy distribution of charged particles along the satellite trajectory, as well as ion and electron temperatures and the potential of the vehicle with respect to the ambient. During the initial period the experiment worked satisfactorily. Unfortunately, the unregulated B+ voltage was lost during the first pass over the Kodiak, Alaska, tracking station. However, a total of six minutes of real-time data readout was obtained, covering a lateral distance of 15,000 kilometers. Analysis of the results of the flight showed that both the electron and ion densities varied by over a factor of two during data acquisition. Electron and ion concentrations with an average value of  $7 \times 10^5$  per cm<sup>3</sup> for each sign agreed within a factor of 20 percent. The satellite potential was found to be negative. On the basis of the one complete analysis of the ion and electron temperatures, the ion temperature of approximately 1400° Kelvin was found to be about 40 percent less than the electron temperature.

The above results represented the first simultaneous direct measurement of ion and electron properties from a satellite, and provided important new information on the physical state of the upper atmosphere—including the extent to which thermal equilibrium existed in those regions. They also provided data on the nature of horizontal inhomogeneities in charge density along the satellite



The densities of the nine major neutral constituents of the atmosphere are plotted for the altitude region 90-2000 Km. The curves presented apply to mean daylight conditions. The densities of the constituents at high altitudes have a strong diurnal variation.

trajectory, and the extent to which the satellite charge, and therefore drag, was influenced by changes in the ambient ion and electron content.

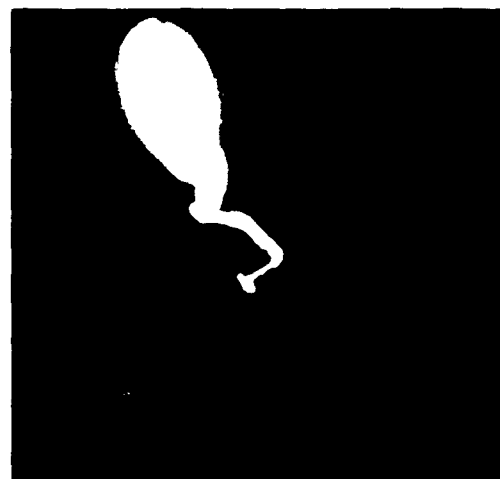
At the close of the period AFCRL scientists were engaged in preparing another spherical electrostatic analyzer experiment to be placed aboard NASA's planned Orbiting Geophysical Observatory satellite, scheduled for a 1963 launching. This experiment also will measure the concentration and energy distribution of charged particles in the upper atmosphere.

**ARTIFICIAL PERTURBATIONS OF THE UPPER AIR:** During the period AFCRL researchers also pursued studies of artificial perturbations caused by the passage of ICBM's and satellite vehicles through the upper regions. A one-year study of high altitude visible missile trails, using a highly-sensitive ground based television system, was completed during 1961. The researchers found that all missiles launched over the Atlantic Missile Range showed trails both during burn phase and for extended periods after burnout. The size, shape, intensity, persistence and spectra of the trails were studied as a function of altitude, exhaust products and missile characteristics. The total radiation emitted in the 4000 to 6000 Angstrom region varied with altitude in a manner similar to that already well established in the infrared.

Most night trails were explained as emission at the surface of a pressure-equilibrated column of exhaust gases initially unmixed with the ambient. Most sunlit trails apparently were solar scatter from exhaust products 0.1 to 10 microns in size, which came to rest in the ambient if ejected during burn phase, or moved along the vehicle trajectory if ejected after burnout. The study of these missile trail perturbations, whose purpose was to identify processes which might permit improved

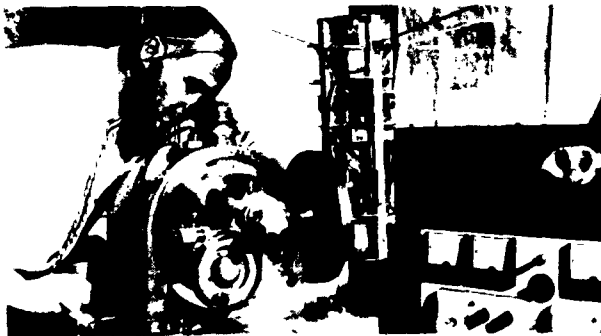
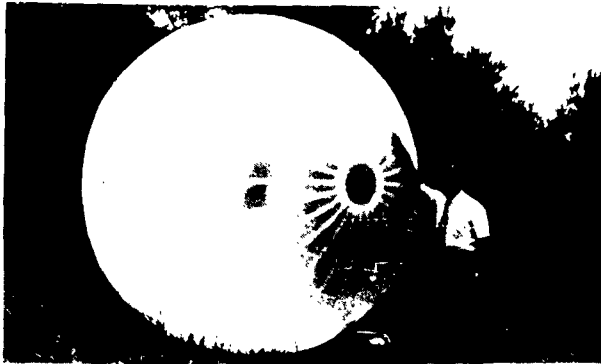


The system shown is used to generate nitrogen and oxygen atoms in known amounts to determine the sensitivity of flyable mass spectrometers are these species. The nitrogen atoms are produced by a microwave discharge on flowing nitrogen molecules; the oxygen atoms are produced by titrating the nitrogen atoms with nitric oxide.



Much can be learned of wind characteristics of the extreme upper atmosphere by the study of missile trails. The visible portion of this trail is about 300 miles long. From the study of the trail, AFCRL scientists can determine the turbulent structure, regions of high wind shear and atmospheric density of the extreme upper atmosphere.





The photos in this series are concerned with the measurement of atmospheric densities in extreme upper atmosphere. The method consists of ejecting a nine-foot inflatable sphere at an altitude of between 80 and 100 kilometers. In the center of the sphere, supported by an inflated cylindrical strut are linear accelerometers and telemetering equipment. After ejection, the sphere continues to an altitude of approximately 250 kilometers. In the second photo the accelerometer is calibrated by tipping the unit into the earth's gravity field. In the bottom photo, calibration repeatability is verified with the help of a very accurate dividing head.

detection and tracking capabilities, was continuing at the end of the period.

**ARTIFICIAL CLOUDS:** The AFCRL investigations of upper atmospheric processes also included the analysis of data obtained from Project Firefly, a high altitude chemical release program begun in the summer of 1960. Clouds of gases and minute particles were injected into the upper atmosphere at preselected altitudes by detonating suitable chemical mixtures carried aloft by Nike-Cajun and Honest-John-Nike rockets. By studying the rate of dispersion of these materials, AFCRL scientists were able to deduce various physical properties of the regions involved. Thirty-three releases were made in 1960, and additional releases were planned for the fall of 1962.

About one-half of the Firefly experiments generated electron clouds whose physical characteristics, formation and diffusion were analyzed. Some of the most spectacular releases were those involving high explosives to study shock waves. Light emitted, when analyzed spectrographically, served to identify the composition of the region where the shock occurred. Atmospheric density also was partially revealed during the 1960 experiments. The motion of the minute solid particles of known size were observed by scattered sunlight, the rate of their expansion providing an indication of the region's density.

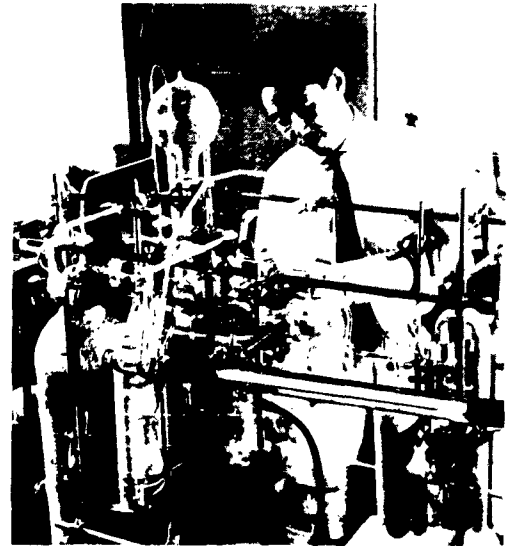
In connection with the additional Project Firefly experiments scheduled for the fall of 1962, during the period a new ionosphere sounding station was constructed at Fort Walton Beach, Florida, to support the AFCRL launch program.

**SPECTROSCOPIC STUDIES:** The complex mechanisms responsible for the composition of the upper atmosphere — that is, the interactions of free atoms,

ions and electrons with sunlight and radiations from space — were of prime interest to AFCRL investigators. One method of analysis of those mechanisms was to study the absorption and emission spectra of atmospheric gases. This research was primarily concerned with the structure of such gas molecules as oxygen, nitrogen, nitric acid, carbon dioxide, helium, etc. During 1961-1962 most of the effort was devoted to the nitrogen molecule because of its abundance and importance in the atmosphere. The technique used was that of spectroscopy, both emission and absorption.

The spectral regions in which studies were conducted included the 600 to 1500 Angstrom region, the vacuum ultraviolet. Many of the so-called forbidden band systems of nitrogen were observed in the region 1050 to 1500 Angstroms. From studies of the afterglows of nitrogen, AFCRL researchers developed a new method of producing the green or so-called auroral afterglow and the resulting spectrum of that afterglow was extensively investigated. The rare gas continua developed in the laboratory, which were essential in absorption studies in the 600 to 1500 Angstrom region, also were considerably improved. The wavelength region covered by each rare gas continuum was extended and the intensity of each continuum increased. The absorption spectrum of molecular hydrogen in the spectral region 800 to 2000 Angstroms was studied in great detail.

As part of the direct effort to obtain new data on the absorption spectra of the upper atmosphere, a number of rocket-borne experiments were conducted during the period. Several grazing-incidence telemetering monochromators were constructed, calibrated and flown into the upper regions on Aerobee rockets. During one successful flight on 23 August 1961, data were



A liquid nitrogen trap removes impurities from tank-type gas before it is introduced into the discharge tube. The discharge tube is the source of radiation for the particular experiment being performed.

obtained on solar extreme ultraviolet photon flux between 250 and 1300 Angstroms and the UV attenuation in the altitude regions between 120 and 225 kilometers. Higher spectral resolution was obtained than in earlier flights, which provided useful data for solar-spectrum analysis as well as for terrestrial aeronomy.

In other successful launchings on 12 October 1961 and 6 March 1962, grating-type spectrographs were carried aloft at the White Sands Missile Range and spectrograms were taken of solar radiation below 2000 Angstroms through long atmospheric path lengths at sunrise. All equipment was recovered in excellent condition, and data were obtained on atmospheric composition in the altitude regions 85 to 160 kilometers. The data from the October flight consisted of seven spectrograms of the solar spectrum with atmospheric absorption



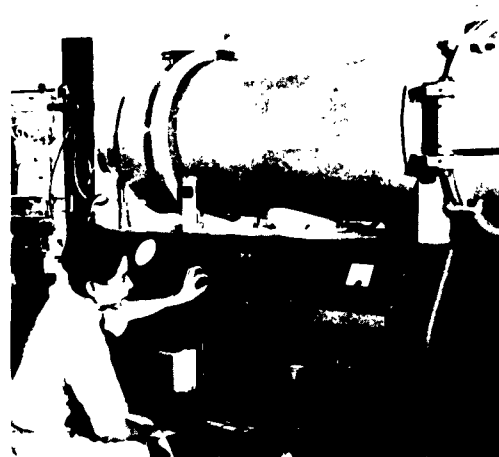
Pressure in the 3-meter normal incidence vacuum spectrograph is checked prior to further evacuation with the oil diffusion pump.

superimposed, yielding information on molecular oxygen distribution in the 100 kilometer altitude region. Other successful flights on 5 and 12 June 1962 brought in additional data on solar radiation between 250 and 1300 Angstroms.

AFCRL laboratory studies were directed toward an understanding of the charge transfer processes and ion dissociation reactions which follow photo-ionization reactions in the upper regions. Since those processes are extremely rapid, with the end products in many cases being identical to the starting products except for a difference in charge, an advance in the state of the art of drift-tube mass spectrometry was needed to combine the functions of the reaction chamber and the analyzer into one unit. Toward this end a modified mass spectrometer was developed, capable of separately measuring species of molecular weights 1-200 at concentrations down to  $10^{-12}$  atmosphere, integral with the reaction vessel in which the charge transfer occurs. Following determination of the reaction cross section of nitrogen, more complex electron transfer processes were to be studied with the modified device.

To determine the rates of certain reactions involving low energy charged particles, an AFCRL contractor studied several photochemical reactions occurring under the influence of the ultraviolet components of sunlight. A quadrupole mass spectrometer equipped with a Seya-Namioka monochromator and a suitable optical line was used to study the photo-ionization of nitrogen, and a photo-ionization efficiency curve was constructed covering the wavelength region from the photo-ionization threshold to about 550 Angstroms. Development of a high intensity continuum source in this region was expected to result in a more detailed description of the photo-ionization process.

AFCRL scientists additionally conducted studies directed toward evaluation of rate constants of reactions leading to formation of nitric oxide from oxygen ion reactions with nitrogen molecules. This process was considered an important source of upper atmosphere nitric oxide, which in its ionized form was a major counter ion to D and E region



The 3-meter grazing incidence vacuum spectrograph is used for rapid exploratory type experiments in the wavelength region 200 to 2000 A.

electrons. The studies set an upper limit in this rate constant, not previously available, and radically lower than had been postulated by other investigators. It appeared to require a major reassessment of formation mechanisms for that important species.

In the theoretical area, some rather extensive calculations of charge transfer cross sections were completed by the Space Physics Laboratory during the period. Cross sections were calculated for protons passing through atomic hydrogen gas and atomic helium gas. In the helium capture problem, cross sections were calculated for 11 different final states. For the corresponding hydrogen capture problem, cross sections were calculated for several different final states.

As part of in-house investigations of proton impact phenomena, AFCRL personnel constructed an apparatus in which protons were accelerated to energies between 3,000 and 30,000 electron volts. The protons were shot into

an observation chamber in which low pressure nitrogen or oxygen were subjected to impacts. The subsequent light emissions were analyzed, their intensities measured and the cross sections for excitation by proton impact calculated. From this research, which was continuing at the end of the period, new data were expected to be accumulated on such atmospheric phenomena as the aurora (discussed elsewhere in this chapter), and the airglow.

**AIRGLOW MEASUREMENTS:** The study of airglow — that is, atmospheric light emissions in the night, twilight and day skies — was pursued by AFCRL scientists with major emphasis during 1961-1962 centering on analysis of data for emissions of atomic oxygen. From this work the midnight maximum of the red line intensity at the equator was confirmed (using data obtained at Huancayo, Peru). This was in contradistinction to the red line behavior at temperate latitudes where the intensity remained fairly steady throughout the night except for the twilight enhancements.

The AFCRL analysis of airglow also suggested that the dissociative recombination mechanisms for the production of the red line were adequate to explain the behavior during both magnetically quiet and magnetically disturbed periods, when account was taken of changes in molecular density. A general classification of the 6300 Angstrom airglow emission at Sacramento Peak, New Mexico, was broken down into three types: Type I, during magnetically quiet nights and characterized by a monotonic decrease of intensity after sunset to a steady intensity during the night, then an increasing intensity as dawn approached; Type II, during magnetically disturbed nights, showing an intensity maximum toward the north northeast,



The 50-cm vacuum monochromator is useful in rapid quantitative determinations of ultraviolet radiation in experiments where high dispersion is not essential.

the direction of the magnetic pole; and Type III, occurring on magnetically quiet or magnetically disturbed days, and occasionally simultaneously with Type II behavior.

In late January 1962, in a daylight airglow collection effort, an Ebert type scanning spectrophotometer was launched from Eglin AFB aboard an Astrobee 200 rocket. This device gathers light in the spectral regions from 2000 to 8000 Angstroms, separates it into various wave lengths which focus on a photomultiplier tube. The latter acts as a light meter to convert the light into electrical energy which, after being fed through an electronics system, is telemetered to the ground. During the January flight the experiment reached a height of nearly 250 kilometers and 10 minutes of data was received. At the close of the period, the work of analysis was continuing.

#### INFRARED RESEARCH

While the physical and chemical properties of the upper regions were being studied by personnel of the Space Physics Laboratory, scientists from the Optical Physics Laboratory were pursuing research into basic infrared physics and infrared transmission through the atmosphere. These studies, which centered on a number of Air Force problems including detection, identification and guidance, were supplemented by an extensive and closely-related contractual effort.

During 1961-1962, as one phase of its work, the Optical Physics Laboratory conducted experimental and theoretical research on infrared geophysical background effects and attenuation against which target sources must be detected. This included a study of the infrared spectral and temporal distributions of the sun, moon, stars, cloud cover, terrain and infrared sky emission. An impor-

tant part of the research involved development of advanced infrared detectors for use in radiometers and spectrometers.

Another part of the Laboratory's assignment involved a program to precisely measure the absorption band intensities of various atmospheric gases\*, to obtain better values for the amounts of absorption or emission of those gases. Existing techniques made use of high pressure absorption cells to pressure broaden the gas so as to reduce the spectral slit correction. The results for the fundamental absorption band of nitric oxide (NO) agreed with those obtained from dispersion measurements. To measure the band intensity using the refractive index of the gas, interferometric techniques were being developed. This method was also to be used for absorption bands of ozone and water.

AFCRL scientists additionally were engaged in a program to measure the effect of scattering to the attenuation of IR radiation by the atmosphere. Part of this work involved theoretical computations of Mie scattering by a contractor. In-house and with contractual support, measurements of atmospheric scattering near the sun's limb also were made, while results of an extensive set of measurements of absorption by atmospheric gases over long paths at low pressure were published. To verify theoretical predictions, these studies were extended to the absorption by two gases in the same spectral region.

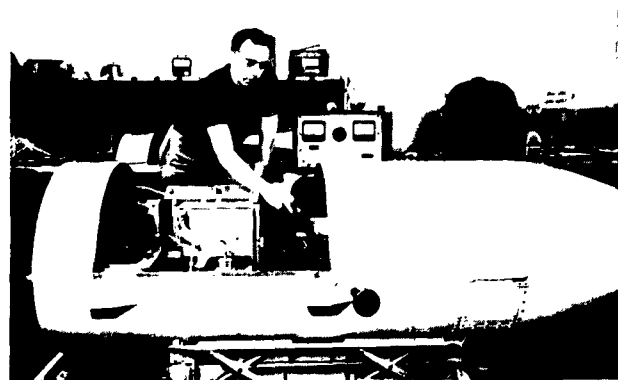
Another in-house effort included a series of balloon flights of interferometers and spectrometers to measure the outgoing flux for comparison with heat balance computations. The Laboratory brought into play one of the most powerful infrared spectrometers in the

\* For the Optical Physics Laboratory's work in Plasma Physics, see Chapter VII.

world for conducting high resolution studies, as well as one of the largest far-infrared interferometric modulators. The importance of the latter lay in the fact that the pure rotational spectra of many molecules was in the far infrared spectral region, extending from about 50 to 1000 microns and many of the lasers and masers under development were being designed to work in that spectral region.

In the search for improved methods of infrared radiometric and spectrometric measurements, the development of several instruments was pursued with considerable attention given to the use of interferometers, as noted above. For the infrared region beyond 100 microns, the optics and drive system were improved for the large glass lamellar grating modulator interferometer. The electrical output was digitized and a complete Fourier analysis data reduction program was set up for a computer. Studies on the pressure broadening of the pure rotation lines of gases included  $H_2O$ .

A smaller version of the lamellar grating instrument also was under development along with an analog Fourier transform computer, which was needed to reduce the use of the larger expensive computers for much of the data analysis. A related in-house development was a Michelson interferometer for use on a telescope to obtain infrared spectra of the emission of cool stars and the absorption spectra of planetary atmospheres. A new far infrared spectrometer, being developed by a contractor, was nearing completion at the close of the period. This device involved the use of a lamellar grating interferometer as an order sorter in an otherwise conventional grating spectrometer. A new double pass optical system for the echelle-grating, hind-prism spectrometer, also under development, was to be used to obtain the best spectral measurements to date



The installation of a radiometer-spectrometer on an Atlas throw-off pod, is pictured. The instrumentation will measure heat radiation during the late launch and early reentry phase of the missile.

on long wavelength bands of ammonia and nitrous oxide. Investigations also were being pursued on applying a cooled germanium bolometer to those experiments. In addition, studies were conducted on the combination of a Fabry Perot Etalon with the spectrometer in order to increase its resolution threefold.

While the above progress in infrared instrumentation was being recorded, basic studies were going forward to obtain a better understanding of the emission of infrared radiation from flames and its attenuation by the atmosphere. The Optical Physics Laboratory utilized the high-resolution prism-grating spectrometer to obtain detailed spectra of nitrous oxide and ozone. Seeking to provide interferometric monitoring of the grating drive and digitized readout, the instrument was modified during the period, and extensive computer programs were worked out to analyze the absorption bands. At the same time several AFCRL contractors carried out high resolution studies on various molecules of interest, in the atmosphere and flames.



A small five-pound infrared spectrometer for observing the exhaust plume of an Atlas missile is loaded on a panel (above) at Cape Canaveral. Below the panel is installed on the missile. This IR spectrometer is typical of the many AFCRL piggy-back packages flown on missiles and satellites.



The important supporting contractual research effort, which was closely coordinated by the Optical Physics Laboratory, also included: a complete theoretical analysis of the pure rotation bands of ozone and sulfur dioxide; measurements of the anomalous dispersion of gases to include measurements of line widths as well as line intensity; infrared spectral studies of the stable and unstable oxides of nitrogen to determine their regions of absorption and their structure; theoretical investigations of the infrared characteristics of missile exhaust plumes and measurements of exhaust flames in simulated high altitude chambers; laboratory spectral measurements of various fuel oxidizers in burners and small rocket engines; infrared spectral emissivities studies of rocket exhaust gases for various propellant combinations; and measurements of plume mission as a function of distance from the nozzle.

To establish the visible radiation amplitudes of the sky and ground as a function of altitude, an in-house program of measurements also was conducted during the period utilizing primarily the high altitude balloon vehicle. This work was supplemented by an aircraft visibility program which sought to determine the optical transmission characteristics of the lower and more dynamic earth atmosphere.

The AFCRL visibility program during 1961-1962 was in a transitional stage, while the measuring systems were being adapted to automatic data recording and reduction techniques. But on the basis of continuing analysis of earlier data, coupled with facts available from two photometer balloon flights, Optical Physics Laboratory scientists confirmed that high altitude scattered radiation was less than previously observed. A new program, in its final design stage at the end of the period,

was expected to establish the spectral radiance levels of the sky in the 2000-4000 Angstrom region. During this experimental program, AFCRL planned to use a scanning spectrophotometer with the high altitude balloon as the platform.

As one part of the above program, a theoretical formulation of the light scattering process was undertaken during the period. Tables were published for the exact evaluation of the distribution and polarization of the reflected and transmitted radiation in a plane-parallel atmosphere scattering in accordance with Rayleigh's laws. The effect of large aerosol particle scattering on the polarization of skylight was determined, and the effect of sea surface reflection on sky light values was evaluated.

In related work a tracking system to be used in missile radiation measurement programs was flight tested during 1961. This system consisted of a high performance optical tracker located in an aerodynamic cavity of a KC-135 aircraft. Measurements of missile radiation were to be performed by a Littrow-type spectrometer scanning between .25 and 15 microns. Hopefully, from the results of this program, and the other AFCRL studies of EM radiations, the advanced Air Force techniques and equipments will be developed for the detection, identification and tracking of enemy missiles and satellites.

#### IONOSPHERIC PHYSICS

During the period the scientists of the Ionospheric Physics Laboratory also were pursuing research into the nature of the upper regions, specifically the ionosphere, and such interrelated phenomena as cosmic radiation, aurorae and geomagnetism. Those phenomena all bore on current and future Air Force operations, including radio communica-



The flying ionospheric laboratory is one of two KC-135 aircraft equipped by AFCRL with specialized instrumentation for studying the ionized environment of the upper atmosphere above 40 miles.

tions, navigation, guidance, detection, tracking and intelligence.

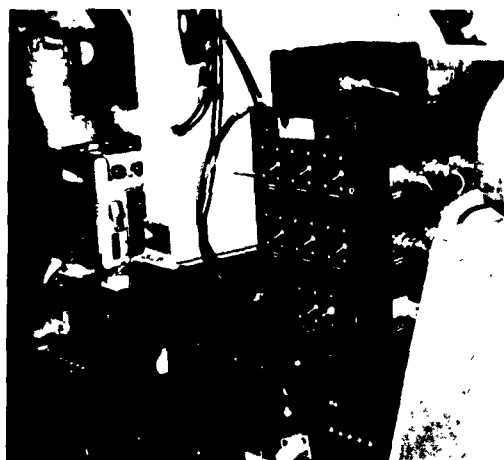
**THE IONIZED LAYERS:** One of the important goals of this AFCRL research was to provide new data on the ionized or radio-reflecting layers from the lowest to the highest levels of ionization in the earth's exosphere. The basic tool was the vertical sweep frequency sounder, utilized by a network of ionospheric stations all over the world to accumulate data. Special airborne, rocket and satellite experiments also provided needed information over otherwise inaccessible regions and altitudes. In general, these experiments involved the transmission and study of the interaction of electromagnetic waves with the ionized regions.

During 1961-1962, using transmitting frequencies of 4.86 and 17.5 Mcps to study ionospheric characteristics in Arctic regions, radio-wave interaction was detected under favorable conditions over a height ranging from 30 to 70 kilometers. The detection of interaction at the lower elevation was unexpected and of considerable interest to the scientists. A change of sign of radio wave interaction was observed for virtual



heights in the 50-60 kilometer range on several occasions. Values for the collision frequency were computed from observations of this sign change. One determination showed a value of  $2.26 \times 10^7/\text{sec}$  at 53 kilometers altitude, and a value of  $1.22 \times 10^7/\text{sec}$  at 65 kilometers. Tentative values of electron density at various altitudes were determined. For example, at 30 kilometers electron densities from 10 to 75 per cubic centimeter were calculated, the lower value being encountered the most frequently. It was suggested that the observed radio wave interaction at the lower altitude may involve modification of the electron density induced by the disturbing transmitter as well as a modification of the collision frequency. However, this theory was in the development stage and insufficient information was available to pursue it further.

In November 1961, to accumulate additional data on ionospheric electron densities, an antenna impedance probe was launched aboard a Discoverer satellite from Vandenberg AFB. The impedance



Among the many equipments in the KC-135 ionospheric flying laboratory is an infrared spectrometer shown on the far side of the table. A power supply is in the foreground.

measuring system used was a standing wave technique at 7.2 Mcps. Forty real-time readouts of the measurements were made at the rate of 5 per second at four different satellite tracking stations. In addition, 17 tape readouts were available, varying in coverage from one-half orbit to two orbits with measurements being made every second.

The Discoverer satellite achieved a near-polar orbit with a 250 kilometer perigee and a 1000 kilometer apogee. The launch time and orbit were such that the perigee of the vehicle always was in the sunlight, and its apogee always on the dark side. The electron densities measured at perigee below the peak of the  $F_2$  layer compared favorably with ionosonde data. On the night side above 600 kilometers the electron density was almost constant with a value of about  $3 \times 10^5$ . On some of the orbits a pronounced peak with up to  $2 \times 10^5$  electron/cm<sup>3</sup> was observed at 650 kilometers in the southern auroral zone. A systematic change of the results occurred as a function of position on the globe. Also, day-to-day variations in the vicinity of perigee in the E layer were observed.

In their studies of the E layer, AFCRL scientists during 1961 gave special attention to analysis of data relating to sporadic E—heavily ionized and random clouds found at altitudes ranging from about 60 to 100 kilometers. Depending on the particular transmitting frequency, the layer was able to absorb a signal or reflect it, with the latter resulting in transmissions to great distances. To collect the needed data for these sporadic E studies, AFCRL researchers called on radio amateurs reports as well as the extensive data collected during the International Geophysical Year (1957-1958).

On the basis of a partial analysis of these data, the Ionospheric Physics Laboratory reported a pronounced peak

of sporadic E activity in the continental U. S. during the months of May, June, July and August. During those months at least one sporadic E cloud reflecting 50 Mcps signals over a distance between 600 and 2000 kilometers was present 20 percent of the time. The corresponding percentage for December-January was only four percent, and was even lower for the rest of the year. There also appeared to be a diurnal distribution of sporadic E activity, with a broad maximum in the evening hours of summer months amounting to 36 percent of the time between 1800 to 2100 hours over the entire U.S. A second maximum of 32 percent occurred during the hours between 0900 and 1300 hours. The low value of the minimum — less than one percent around 0300 and 0400 hours — was a less reliable figure because of lack of sufficient data provided by the radio amateurs.

AFCRL scientists also found that the geographical distribution of sporadic E clouds over the nation was not uniform. The highest local activity was over Missouri, with the heavy concentration over that state and surrounding areas being something of a mystery. Analysis of data supplied by radio amateurs showed that the average sporadic E cloud generally is about 600 kilometers in diameter. They usually last for several hours, and while they move somewhat irregularly there was a predominant easterly motion with an average velocity of 250 miles per hour.

In related work, a computer technique was developed by AFCRL scientists for solving the complex system of rate equations in the atmosphere. These differential equations, which describe the time rate of change of the number density of the chemical constituents, can predict the ionization present at any time at any point in the atmosphere. The technique functions satisfactorily from 20 km up



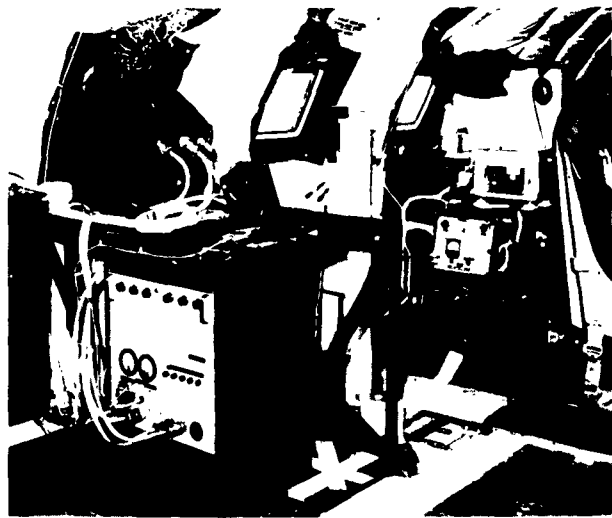
Elaborate ionospheric sounder equipments are arrayed along one side of the flying laboratory.

to 200 km. Since transport mechanisms and diffusion were not included, it can not yield reliable results above 200 km where these phenomena become important. The computer program was capable of functioning efficiently with any number of individual chemical species and with any number of chemical reactions.

As part of their studies of ionospheric motions in the E region, AFCRL scientists designed a space receiver experiment using a frequency of 60 kcps, and they carried out a study of drifts over a particular period. The important properties of the ground pattern, axial ratio and tilt angle were determined, the mean value of this ratio being 1.2. They concluded that the diffraction pattern on the ground, at a frequency of 60 kcps, was essentially isotropic with a mean

structure of about 5 kilometers which did not vary much with the time of night. From analysis of the drift velocities in the E region, speeds were found never to exceed 20 meters per second in any direction, with a mean value of 4 meters per second in the southeast quadrant, repeating from night to night and from hour to hour.

In also seeking to extend their knowledge of ionospheric characteristics beyond the F<sub>2</sub> region, where conventional sounding techniques were not usable, AFCRL scientists pursued a number of theoretical and experimental investigations of natural extraterrestrial radio noise in the low radio frequency range known as "whistlers". By measuring and analyzing the transmission characteristics of whistler signals with respect to their physical features, data were provided on auroral, geomagnetic and ionospheric phenomena. A station for analysis of relations between lightning discharges and whistlers was operated near Uppsala, Sweden, where



In the foreground, covering the window and shielded from light from inside the KC-135, is a photometer. Two specialized spectrometers are also shown.

it was found that whistlers occurred in groups with periods of one-half to 2½ hours and occasionally of 5 and 6 hours. Sometimes whistlers occurred in great numbers for shorter periods of time between total cessations. These extended over hours, days and even weeks. It was also found that while a thunderstorm in one direction produced whistlers, a simultaneous thunderstorm in another direction at about the same distance sometimes did not.

In the same thunderstorm, variations of the electric field strength from sferics related or not to whistlers showed that lightning discharges with the highest field strength were always followed by whistlers. This was explained by facilitated propagation for wave pockets in the low frequency band around 5 kcps, and by high initial energy in the discharges causing whistlers. A comparison in the same thunderstorm of wave-forms from sferics not producing whistlers showed typically irregular variational forms and one single discharge in the lightning path. Wave-forms of whistlers producing sferics showed regular variational forms with frequencies around 5 kcps. Work in this area was continuing at the close of the period.

**COSMIC RADIATIONS:** The requirement for additional data on cosmic radiations, in particular as concerned their possible damaging effects on Air Force equipments flying through the upper regions,\* also engaged the attention of AFCRL scientists. Both an in-house and contractual program was pursued, with field experiments based both on passive and active sensors sent aloft on various vehicles. These sensors included nuclear emulsions, gas proportional and geiger counters, scintillators and solid state

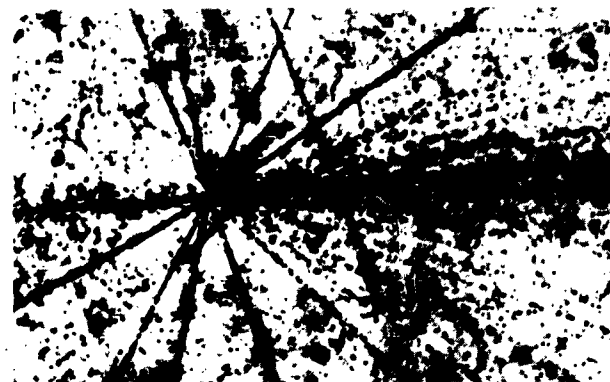
\* See also the discussion of AFCRL radiation effects studies in Chapter III.

detectors. In different ways, these devices are able to detect the passage or track of a charged particle in the upper regions.

One of the most successful programs of AFCRL's cosmic radiation studies centered on sensors placed aboard Air Force Discoverer polar-orbiting satellites. These flights provided important new data concerning the intensity of cosmic rays and trapped Van Allen particles in the near-earth environment. Thus, for example, some 12 capsules in the Discoverer program, recovered after re-entry, contained AFCRL emulsion block detectors. The very first emulsion recovery from Discoverer 17 had followed exposure to a large 3 $\div$  solar flare in November 1960 which greatly overexposed the sensitive film. However, AFCRL scientists developed special techniques of processing, which made it possible to gain useful data from the film. The other eight flights took place during periods of more or less normal solar activity during 1961-1962. These varied exposures provided Ionospheric Physics Laboratory scientists with a unique opportunity to study the complex spectrum of ionizing particles constituting the solar and galactic cosmic radiation.

The Discoverer program was particularly useful in the study of cosmic radiation because the polar orbits resulted in transversals of near earth space in such a manner as to vary the geomagnetic cut-off effect inversely from zero to maximum. In addition, the vehicles' positions above the sensible atmosphere eliminated the absorption effects which makes impossible the study of the low energy end of the spectrum from the ground.

The emulsions were studied systematically by AFCRL scientists for nuclear events (star production) as an index of the flux of the more energetic cosmic and



The simplest and most economical way to measure high energy particles is by photo emulsion techniques. When a high energy particle strikes an atom in the emulsion material, a "star" of the type shown in the above photograph is produced. Energy of the particle is measured by the number of star prongs produced.

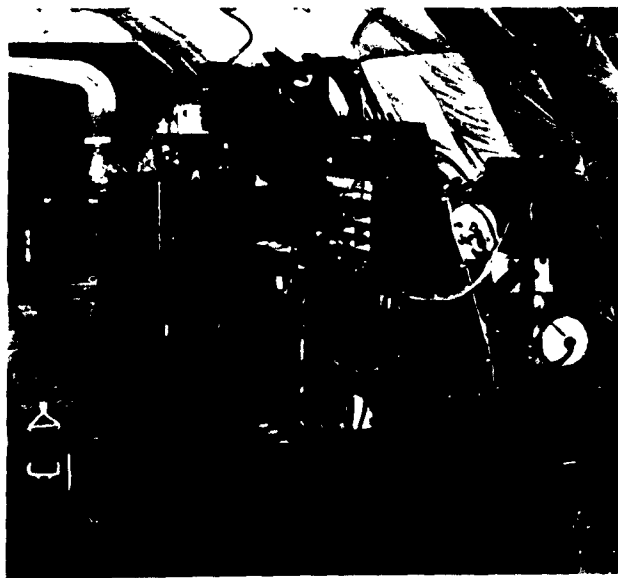
trapped nucleonic radiations. In the lowest orbiting satellite, they found that radiation levels were similar to that observed by early measurements on balloons and vertical rocket probes over stations at different geomagnetic latitudes. On the other hand, a Discoverer whose apogee was 695 kilometers brought the emulsions into the lower fringes of the Van Allen belt and showed an enhanced average star production rate of 6790 cc<sup>-1</sup> day<sup>-1</sup>. This compared with the low orbit flight whose star production rate was 2240 cc<sup>-1</sup> day<sup>-1</sup>.

One of the interesting observations that followed the flight of Discoverer 17, by scientists of the Smithsonian Astrophysical Observatory who examined parts of the vehicle provided them by AFCRL, was that the metal contained unusually large amounts of tritium. Although tritium (hydrogen 3) could be produced in the satellite materials by bombardment by high energy particles, the concentration was too high to be explained by that process alone. In a

follow-up study, the scientists were able to provide a quantitative analysis to show that the large amount of tritium was present in the solar flare material and therefore had been produced in the sun's atmosphere. An analysis of the emulsion aboard Discoverer 17 showed a flux of carbon-like nuclei in the flare-exposed emulsion 100 fold greater than present in the normal galactic beam at the same energy level, which indicated the ejection of such nuclei from the sun during flares.

Other cosmic radiation experiments flown on Discoverer vehicles during the period included geiger counters, scintillators, proportional counters, solid state detectors and neutron monitors. These experiments provided valuable data on the type and energy spectrum of the particulate radiation near our planet.

Scintillators and geiger counters also



A neutron detector (right foreground) and a cosmic ray detector (left rear) carried aloft in one of AFCRL's KC-135's permit AFCRL to measure man-made and natural high energy particle fluxes up to 50,000 ft.

were flown on vehicles which traversed the inner Van Allen belt. Their unique orbit in the heart of the belt provided the first data on proton distribution in that portion of the belt which has the highest proton concentration. The data showed that the concentration of the belt is higher than previously estimated, and that the spectrum varies rapidly with change in altitude at the magnetic equator or equivalently with magnetic L value. Towards the close of the period plans were being formulated to study this effect in greater detail, possibly utilizing vertical rockets fired from the magnetic equator.

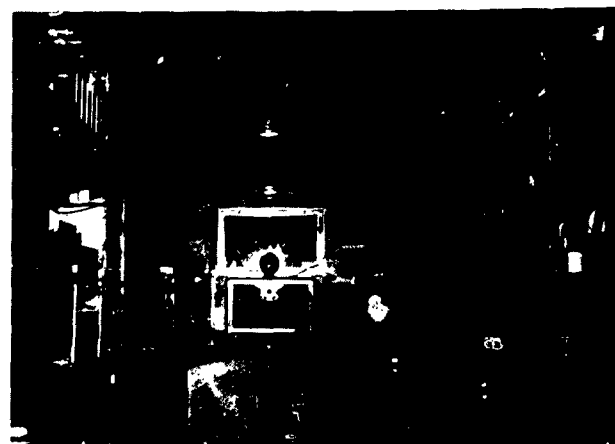
**MAGNETIC FIELDS:** Another area of AFCRL interest involved the "permanent" and transient magnetic fields in the earth's atmosphere and surrounding space. Investigations begun of transient magnetic fields were aimed at: (a) developing descriptions of the basic characteristics of the phenomena in forms suitable for comparison with theories concerning their origins and with other geophysical or solar phenomena; and (b) evaluating, modifying and developing theories to account more adequately for observational data. Investigations on the main magnetic field of the earth, the "permanent" field, were directed toward developing the most accurate description of the field as a function of time and position in the space surrounding the earth.

Prior to 1961 a variable-area magnetograph was developed for this program to eliminate the need for manual scaling of the magnetograms. Also development was initiated on a photoelectric scanning device and a digital data reduction device for the rapid processing of the variable-area film records from the magnetographs. To record magnetic variations as a function of latitude, magnetographs were in-

stalled at a chain of four stations along the 75° west meridian at Godhavn, Greenland; Weston, Mass.; Fredericksburg, Va.; and Huancayo, Peru. An additional station at Kiruna, Sweden, yielded additional auroral-zone recordings. The variable-mu magnetometer, a high sensitivity frequency-modulated oscillator device whose output frequency was proportional to the applied magnetic field, also was developed. This device was later adapted for rocket measurements under other programs.

During 1961-1962 the variable-area film scanner was completed under contract, and a data assimilator, digitalizer and analyzer was constructed and coupled to the film scanner. Improvements in the variable-mu magnetometer sensitivity were achieved, and trial recordings on magnetic tape of the frequency-modulated output were made. While variable-area recordings at the chain of field stations were planned for several new stations at Cuzco, Peru, and Ellsworth, Antarctica. In connection with this work, an AFCRL contractor completed a study of 346 magnetic storms that occurred from 1902 to 1945. The division of the storms into three categories of increasing intensity yielded better information on several phases of storm morphology.

In studying the nature and origin of short-period geomagnetic fluctuations, AFCRL/contractor personnel concentrated on the 1 to 50 cps frequency range. Adequate data-samples of the three-component tape recordings of the 1 to 50 cps fluctuations at Thule, Greenland, Fort Devens, Mass., and Denver, Colo., were completed during 1960 and at Huancayo, Peru, in February 1961, and the emphasis in this program turned to the reduction and analysis of the data. A semiautomatic data reduction program, begun during 1960, was continued during the reporting period and a good



In this AFCRL trailer is the receiving equipment and real time read out instrumentation for telemetered magnetometer data received from rockets.

start was made on preparing tables of average signal levels in octave frequency bands.

The AFCRL analysis to date indicated that most of the 1 to 50 cps fluctuations, as expected, originated in world-wide thunderstorm activity and were modified by propagation in the earth-ionosphere waveguide. The unexpected discovery of 1.5 cps quasi-sinusoidal geomagnetic oscillations associated with meteor showers proved of great interest, since such hydromagnetic phenomena had not been predicted by existing theory of the lower ionosphere where the meteors expend their energy.

As part of this research, on 18 April 1962 an Astrobee 200 rocket was successfully launched from Eglin AFB, carrying instruments for measuring total magnetic activity, positively charged particle density counters, and magnetic and optical aspect sensors. All sensors functioned normally, however, there was a telemetry reception problem and data received was being analyzed at the close of the period. In an earlier series of four launchings from Holloman

AFB, Eglin AFB and Fort Churchill, Manitoba, data had been obtained on hydromagnetic waves in the ionosphere and auroral magnetic disturbances.

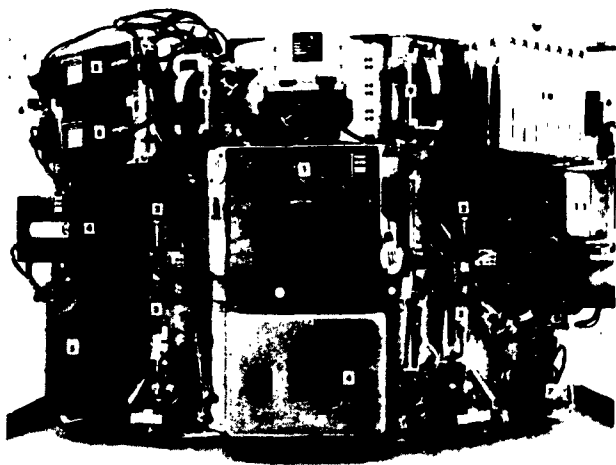
To determine the magnetic field of any point, a special AFCRL computer program was written during the period utilizing any given set of Gaussian coefficients. As part of the program, several sets of rocket magnetometer data were compared with the theoretical predictions. Using a vector airborne magnetic survey in conjunction with a rocket magnetometer flown in the same area, a special extrapolation technique also was devised and programmed. Extrapolation from the airborne survey was to be compared with observations made in the rocket.

During the period, to meet the need for more accurate specification of the magnetic field, a new in-house method for performing a spherical harmonic

analysis was developed and verified. The new method was based on the Schmidt process, which orthogonalizes a set of vectors in a multi-dimensional space and guarantees a numerically-accurate solution, and on a statistical truncation criterion which finds the best set of coefficients from any given set of magnetic field data. Using this method a set of magnetic observatory data yielded Gaussian coefficients for epoch 1960.

To improve their theories of magnetic and ionospheric storms, AFCRL scientists at the end of June 1962 were planning a series of experiments to investigate shock wave phenomena in the auroral region. These included balloon experiments to record data of an acoustic disturbance coincident with the arrival of the shock wave, and a program of five rocket launchings beginning in late 1962 into the auroral region. In earlier studies investigators had noted particles trapped in a magnetic dipole field caused two distinct magnetic effects: (a) The gyration about the lines of force gave rise to a magnetization current which produced a positive perturbation interior and exterior to the trapped particle region; and (b) the particles drifted in azimuth and the resultant ring current decreased the driving field interior to the trapping region and increased it to the exterior. At the dipole center this effect was opposite to and three times as large as the diamagnetic effect.

During the period explicit expressions were obtained for the current and the perturbed field, observed as one progressed radially outward in an equatorial plane through the outer radiation belt. A maximum current density of about  $10^{-8}$  amp/m<sup>2</sup> flowed in the vicinity of 30,000 kilometers geocentric distance. The total current was of the order of  $5 \times 10^6$  electrons per cubic meter (at 25,000 kilometers), the magnetic field anomaly was of the order of  $-100$  to



Typical of the instruments flown aboard Discoverer satellites is a package shown here. Instruments include such items as beta-gamma detectors for ion trap probes, impedance probes, tape recorders, system timers and so on. Usually several agencies including AFCRL will all ride piggyback on a single satellite package which was the case here.

—250 gamma, depending on how sharply defined the inner edge of the radiation belt was.

With the help of the above expressions, the "magnetic signature" of any reasonable trapped particle distribution seemed capable of being synthesized, provided the gradient of the total field thus obtained was nowhere positive. The calculations appeared capable of explaining the Explorer VI results in terms of a radiation belt of limited radial extent, in the vicinity of 40,000 kilometers. While difficulties arose in explaining the "fine structure" at 21,000 kilometers in the Lunik I results, the gross behavior of the magnetic field was fairly well reproduced.

**AURORAL PHYSICS:** The Ionospheric Physics Laboratory also was engaged in studies of auroral phenomena through direct field observations, laboratory studies and theoretical interpretations of observed data. This research included investigations of solar-planetary auroral relations, auroral morphology, excitation mechanisms, radio interaction mechanisms and nuclear-induced aurorae. The association between auroral activity and magnetic disturbances was a part of these investigations.

To determine the dependence of aurorae on magnetic activity, and to gain new knowledge of diurnal and seasonal variations, all-sky camera data obtained at a southern hemisphere station were analyzed. The scientists found that in New Zealand, local magnetic activity was the most reliable predictor of auroral occurrence. Data from several northern and southern hemisphere sites were subsequently collated and reduced to a form suitable for eventual correlation studies using electronic computers. During 1961 the design and construction of an automatic recording densitometer for detailed analysis of various patrol spectrograph

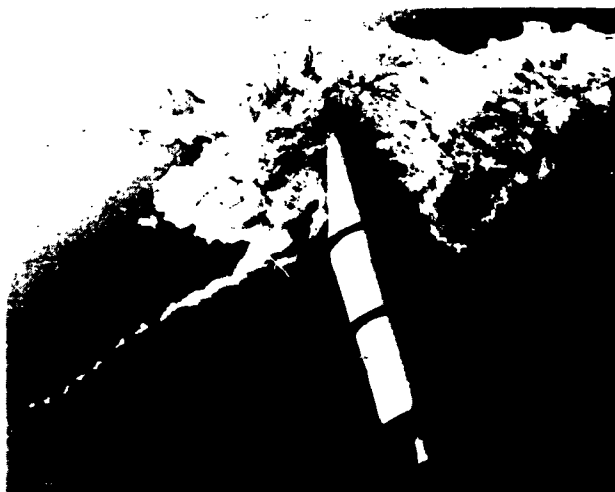
data was completed, and digital punched card capability was incorporated into the instrument. A comprehensive in-house synoptic data reduction program was planned as a future activity.

During their investigations of the relationship between aurorae and magnetic disturbances, scientists were particularly interested in the reasons why bright auroral displays were often observed during quiet magnetic conditions, while large magnetic storms did not always produce visual aurorae. From a study of spectrograms recorded in the Arctic and Antarctic, they were able to offer an explanation to the second part of the phenomena. According to this explanation, aurorae were in fact produced at all times during magnetic disturbances, but that they were not always visible.

They found that spectrograms of the light emissions from aurora showed a characteristic pattern, a predominant feature being nitrogen emissions at 3914 Angstroms. During periods of high magnetic disturbance, the nitrogen emissions existed as extensive glows. For the observer within the auroral zone, this glow was of such intensity that any low contrast auroral forms were not apparent. These conclusions, based on AFCRL monitorship of night-sky emissions in the polar regions since the beginning of the IGY, covered six major solar events and the resultant magnetic disturbances. All six events followed the same pattern. Soon after the onset of the magnetic disturbance, the intensity at 3914 Angstroms, as observed inside the auroral zones, began to increase steadily reaching a maximum about 24 hours later. This coincided with the activity peak of the associated major magnetic storm. The intensity then fell steadily, returning to its normal nighttime minimum value some 48 hours after the peak.



Normally aurorae occur at altitudes of about 110 kilometers and above. During magnetic disturbances associated with Polar Cap absorption, it appeared the enhanced nitrogen emissions took place at lower altitudes, considerably below 100 kilometers. Support for this view came from the fact that the twilight enhancement of the 3914 Angstrom nitrogen band at normal auroral altitudes became almost undetectable because of the higher intensity of the extended auroral glow below. Riometers (for measuring absorption of cosmic noise) gave evidence of increased absorption in this altitude regime. The most probable cause of the lower altitude optical emission and radio wave absorption (the latter measured by a riometer) was thought to be relatively low energy particles emitted by the sun during violent flares. Other spectral features of the aurorae also exhibited enhancement during the main phase of the magnetic storm, but did not exhibit the steady



An Agena B satellite passes over Alaska in this drawing. The impedance probe antennas are in flight positions, parallel to the earth.

changes over a period of days as did the molecular nitrogen emissions.

In this connection, during the period AFCRL scientists participated in an input-output satellite experiment in which photometric measurements of 3914  $N_2^+$  and several energy ranges of particles were to be made from a polar orbiting satellite as it passed over an auroral display, also being observed by two optically instrumented aircraft under the aurora. An AFCRL KC-135 aircraft successfully obtained auroral spectra but unfortunately because of satellite telemetry failure, the basic objectives of this complicated experiment were not achieved.

As part of the above research, an auroral theory was developed from the point of view of particle orbits in an inhomogeneous plasma confined by a magnetic field. Specifically, a mechanism was proposed for injection into the atmosphere of geomagnetically trapped protons and electrons. The different forms were classified, showing that type A red and sunlit auroral forms gave higher temperatures more frequently than did the normal types. Measurements of the night airglow in the infrared region 1 to 2 microns were made, and partially resolving the hydroxide (OH) bands gave rotational temperatures between 200 and 225° Kelvin.

On the basis of these studies of the excitation of aurora and airglow emissions, several papers were published on the excitation mechanisms which should assist in the interpretation of those phenomena. The mechanisms included new rotational constants of two levels for hydroxide. New examples of atomic recombination involving excited nitrogen atoms were found, and a new unexplained effect in afterglows involving electron decay was noted.

Q During the reporting period the Cambridge Research Laboratories were engaged in several significant programs to uncover new knowledge of the sun, moon and planets, the flux of high energy particles, and magnetic and electromagnetic phenomena within the solar system. This research—conducted by the Radio Astronomy Branch of the Space Physics Laboratory, the Lunar Planetary Exploration Branch of the Research Instrumentation Laboratory, and the Sacramento Peak Observatory—was related to AFCRL projects in aerospace physics and the electromagnetic wave sciences and also drew heavily on in-house and contractor advances in the area of instrumentation technology. The highlight of these studies undoubtedly was the initiation by the Observatory of a solar flare prediction program, which during 1961-1962 provided the Air Force and NASA with data on periods considered “safe” to conduct orbital flights of the nation’s first astronauts and flights of unmanned satellite systems. The story of the solar flare prediction program, as well as the other AFCRL research projects in the space sciences, will be outlined in this chapter.

**THE SAC PEAK PROGRAM**

For more than a decade AFCRL’s Sacramento Peak Observatory in southern New Mexico has been studying solar processes to obtain data which will enable it to predict those outbursts of energetic particles which may degrade Air Force operations within the earth’s atmosphere as well as in outer space. Since its formal establishment as an Air Force research facility in 1952, the

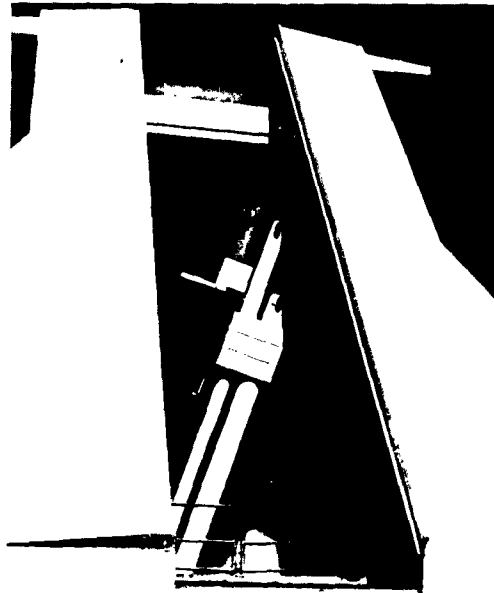
Observatory has used a cluster of small telescopes and coronagraphs in a unique solar patrol program. Solar data from the patrol program are reduced and consolidated each day, and communicated by phone to the World Data Center and the National Bureau of Standards at Boulder, Colorado, to enable predictions of radio propagation conditions. The work of the Sacramento Peak staff is supplemented by a contractual program and the scientific contributions from distinguished foreign astronomers, who receive temporary appointments (six to 18 months) to the facility.

#### THE FLARE PREDICTION PROGRAM:

While the Observatory's major efforts for years have centered on the basic processes of the sun which affect atmospheric radio propagation conditions, during 1961-1962 a new requirement arose for data on solar radiations. Specifically, it was based on a need arising from the launching and operation of satellites, and on plans for the first manned orbital flights. As noted in earlier chapters, several AFCRL groups\* were engaged in various studies of radiation effects on electronic equipment and radiation intensities in outer space. Aside from the dangerous portions of the Van Allen belt, the principal danger centered on the sporadic showers of fast solar protons. Many of the intermittent solar showers would be exceedingly dangerous to an unprotected space pilot, besides being capable of damaging or destroying some types of space craft electronic and photographic equipment.

Scientists for many years have been aware that the dangerous proton showers originate in the largest solar flares of 3 or 3+ importance. These showers reached the earth  $\frac{1}{2}$  to 7 hours

\* The Electronic Material Sciences Laboratory and the Space Physics Laboratory. See Chapters III and VI.



A major part of the Sacramento Peak instrumentation is housed in the above observatory. Mounted on a single spar are five telescopes, including a 16-inch coronagraph, a 16-inch telescope and a 9-inch coronagraph. Below is another view of the multiple-mounted telescopes taken from the interior of the observatory.

after the peak brightness of the flare. They found that only about one major flare in four was a "proton flare," producing a proton shower of dangerous flux and energy. A safe period was defined as a period during which the occurrence of a proton flare was unlikely. Since the least expensive defense against damage or interruption of critical communications was simply to avoid the proton showers, it suggested limiting space operations to safe time intervals.

In March 1961, after receiving a request from the Air Force's Space Systems Division, the Observatory began making daily 5-day predictions of solar activity. The information also was provided to other governmental and private research agencies. From the beginning the Observatory was able to correctly predict all proton showers, although initially it gave many false alarms. That is, at the outset of the prediction program about 80 percent of the time was designated unsafe. With growing knowledge and experience, the AFCRL scientists were able to reduce the unsafe periods to about 30 percent. In recent months, the Observatory predicted safe periods for the first two American manned orbital flights. These Project Mercury predictions were mainly oriented toward possible communications interference, since the orbital trajectories were such that, even if fairly large flares had occurred, critical radiobiological hazards were unlikely.

Since the flares were closely associated with sunspots and shared the same 11 year cycle of activity, the Observatory found that the prediction of safe intervals during sunspot "minimum" was relatively easy. However, at sunspot "maximum" proton flares occur at a rate of about one per month and predictions become more difficult. The last maximum came in 1957-1958. Minimum was expected during 1964-1965, followed by



A general view of the main Sacramento Peak Observatory is shown here. This observatory contains some of the most advanced instruments presently available for solar research.

the next maximum in 1968. Since the 1966-1971 period was to be a time of greatly increased U. S. space activity, and proton showers were expected to occur at a rate of 8 to 12 per year, a formidable prediction problem was anticipated.\*

On the basis of their observations, the scientists were able to relate the large flares to the solar active centers around the sunspot groups. These centers vary enormously in character and only a small fraction actually produce large flares. The problem was to distinguish the flare producers from the less dangerous centers. A number of indices were developed at the Observatory which appeared to be reliable. For example, prime attention was given to centers around the most complex spot groups, with many small spots peppered around a large dominating pair joined by a com-

\* The Soviets reportedly were making plans to try for a manned lunar landing by 1965, their astronomers having cited the dangers for manned space flight during 1966-1970 because of solar flare activity. Both the Gagarin and Titov orbital flights of 1961 were made during "very safe" periods.

mon penumbra. If the scientists found that the center also had a complex magnetic field with numerous poles intermixed, it was considered a likely producer of large flares. To observe the magnetic fields and to obtain data on the other indices, the scientists monitored the emission of raucous bursts of radio noise, the total light absorption of the spot group, and the frequency of small flares in the center.

At first the above indicators served to select the dangerous active centers, and were the only ones used. But additional research showed that the age of the center and its position on the disk of the sun also were important factors in determining whether the flares produced would emit protons to the neighborhood of the earth. It was found that if the center was not at least 18 days old and produced a flare outburst, a proton shower near the earth was very much more probable if the center was in the northwest quadrant of the solar disk, than if it was located anywhere else. This mysterious relationship was so pronounced that of the 12 strongest proton showers on record only three originated in centers outside the northwest quadrant, and they were within a few degrees of the boundary.

The gross characteristics enumerated above as symptoms of proton showers very nearly exhausted the possibilities of features accessible to terrestrial observation. While they were very useful for the periods of low solar activity, it was clear to AFCRL scientists they would not be adequate for prediction when activity increased. In the search for improved methods it was necessary to look deeper into the nature of solar flares and the mechanism of proton emission.

It was theorized that the flare's explosive phenomena could only result from energy stored in some fashion that per-



This series of photographs, taken at roughly 3-minute intervals, shows the growth of a solar flare on the rim of the sun.

mitted the storage to become unstable. The form of the stored energy seemed to be the strong magnetic field of the active centers, with the energy in it being probably a hundred times greater than that released in a flare. Since the chromospheric material was highly conductive due to ionization, the magnetic field was in firm control of all physical activity in an active center.

On the basis of the above considerations, the Sacramento Peak scientists studied the magnetic field as the place to look for the windup which might result in a flare. With sufficiently refined optical equipment (by the Zeeman effect), or by its influence on motions in the active center, they were able to observe the magnetic field directly with instabilities showing up in the form of very steep gradient field strength or velocity. Such gradients were not apparent in the large features being observed during the 1961-1962 period, although the most refined observations did give some indication of their presence in the very small features. The orientation of this phase of the research was, therefore, toward a detailed analysis of the spectroscopic (including Doppler and Zeeman effect) peculiarities of the finest resolvable features. However, since the art of such observations had been advanced to the limit of existing Sacramento Peak equipment, an important research effort was pursued to obtain additional and more refined instrumentation. A description of the existing equipment, plus a review of the newer instrumentation being developed, will be found elsewhere in this chapter.

**TEMPERATURES AND DENSITIES OF PROMINENCES:** The flare prediction program, as has been noted, had developed naturally out of the long-term basic solar research program conducted at the Observatory. One phase of the older continuing effort centered on a study of

the spectra of prominences — those great clouds of solar gaseous materials which reach heights of ten or hundreds of kilometers above the visible surface of the sun (the photosphere), and which are clearly associated with the more complicated flares. The purpose of the investigation was to attempt to specify the temperatures and densities of the various types of prominences found in and outside of flaring regions.

To determine those phenomena the Observatory obtained an extensive series of excellent ultraviolet and infrared prominence spectra for analysis. From these spectra the scientists were able to specify temperature and density with very firm upper limits and less certain lower limits. They found the most probable temperatures varied from 10,000° Kelvin for quiet region prominences to 22,000° for the most active. These values were, however, startlingly different from the extremely high temperatures found by other investigators (100,000° Kelvin) on the basis of supposed temperature broadening of the lines. The line broadening was believed probably the result of mass motions, perhaps turbulent, on a small scale. This phenomena, however, was not entirely clear because of several discrepancies. For example, certain classes of lines were not broadened, including the high excitation lines of He I and He II. It appeared that the discrepancies could be explained in terms of a model of heat conduction proposed by Sacramento Peak scientists; however, definite proof of this required additional observations of much higher resolution than have been achieved to date.

**SPECTRA OF SPICULES:** In related research the scientists pursued the exceedingly delicate task of observing the spectra of spicules at the solar limb and determining the physical condition in



A modified grain-bin is used to house AFCRL telescopes for flare patrol observations. A stop-motion camera takes pictures each minute during the day of the solar disk, and thus a continuous record of solar activity is available for study. Most of this solar flare patrol activity will be moved in the latter part of 1962 to the new observatory, also located at Sacramento Peak, shown below.



them. The spicules are very minute spikes of solar material with all the appearance of jets, sticking up above the chromosphere. At any one time about 1,000 are visible around the whole limb. Because of their faintness, small apparent size and density along the limb, a successful spectroscopic observation was considered a triumph. During the period success was achieved to the extent of photographing high dispersion spectra of clearly separable individual spicules. But as was the case with prominences, interpretation remained difficult since it was found the line widths led to entirely unrealistic temperatures, completely inconsistent with the line intensities. At the close of June 1962 the spicules study was continuing in the effort to learn more about their physical properties.

In the course of attempts to obtain data on the smallest solar spectra, the Observatory succeeded in taking time sequences of very high dispersion spectra showing the apparently random Doppler shifts in very small surface elements on the sun. Subsequently, an analysis was made of the vertical and horizontal motions from the line shifts shown at the center of the disk and at the limb (where the surface of the sun was viewed at grazing incidence). The results of this analysis were a complete surprise and indicated that:

1. The vertical motions in the line-forming layer above the white photosphere were periodic and quasi-sinusoidal.
2. The velocity amplitudes of the oscillations increased with increasing height.
3. The oscillation periods were strongly concentrated around 242 seconds, with a standard deviation of less than 15 percent. This was clear evidence of a resonance effect.
4. There was a decrease in period

with increasing height. Oscillations of the shorter periods showed a definite time lag between high and low level, indicative of upward propagating sound waves. The longer period waves did not show lags, and were apparently standing waves propagating horizontally.

5. The horizontal motions were entirely different, showing no oscillations, and there was a tendency for long enduring large velocities on which were superimposed small random velocities. In summary, the velocity field in the reversing layer was decidedly anisotropic and resonated vertically.

During the period, the Observatory's study of motions in the solar atmosphere was extended to the hydrogen alpha line, which originates much higher in the chromosphere where periodic motions seemed much more improbable than at the lower levels. Unmistakable oscillations were found, although they were less clear cut than for the low level lines. The hydrogen alpha motions were much more strongly related to the fluctuations in the line intensity than was the case for the lower lines, and the motions in the dark elements appeared to be a kind of seesaw.

The observers also noted a very clear relationship between the magnitude of the vertical motion and the distance from the line center at which it was measured. Since they saw deeper into the chromosphere as they went out from the center of the hydrogen alpha lines (simply because there was less absorption), this was considered actually a relation between height and velocity. A similar relationship had appeared in the earlier study of low level lines, and led to the important conclusion that measurements of vertical motions in any lines constituted a new astrophysical tool for ranking them according to height in a completely unambiguous fashion. No two lines showing different velocities



The rim of the sun taken by the coronagraph at Sacramento Peak shows the sun's chromosphere during a relatively quiet period.

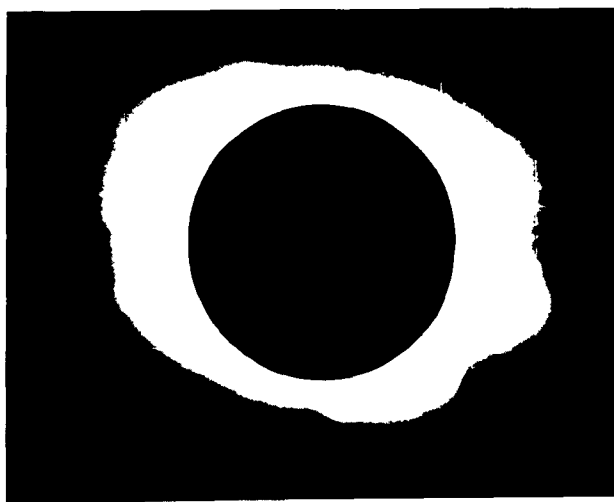
could originate in the same layer of the solar atmosphere.

During another analysis made with the assistance of a visiting astronomer, the spectra of the velocity effects were studied in the K line of Ca II, which originates even higher than the hydrogen alpha line in the chromosphere. This line possesses an entirely different character. Its complexity of structure, with self reversals and violent intensity fluctuations from point to point, makes it exceedingly difficult to study. The analysis indicated that the velocities in the line core were independent of those in the bright emission peaks. If this could be established by quantitative photometry of the spectra, it would indicate a clear separation in height and a near discontinuity in motions near the interface between chromosphere and corona. At the close of the period, efforts to develop better measurement techniques were being pursued.

**SOLAR ECLIPSE EXPEDITION:** Another significant event in the Sacramento Peak program during the period involved an expedition to Lae, New Guinea to observe a total eclipse of the sun on 5 February 1962. Co-sponsor of the expedition was



the High Altitude Observatory at Boulder, Colorado. Unlike two previous disappointing expeditions in 1958 and 1960 (both were clouded out), the New Guinea observations were completely successful. The scientists were able to obtain a motion picture of the spectrum of the chromosphere, with medium dispersion and broad wavelength coverage. Two spectrographs made 4.5 exposures per second between them, covering the range from 3300 to 9000 angstroms. Each exposure covered a 15 x 70 cm film. The total period of observations was 118 seconds, resulting in 530 spectra—which was considered a record for speed in astronomical data collection. The advantage of spectra taken in rapid sequence at a total eclipse was in the fine height resolution provided by the moon's limb. The limb covers (or uncovers) the chromosphere at a rate of 300 km/sec. Exposures at a rate of 3 per second, therefore, have a height resolution of 100 kilometers. This is far beyond the



Certain characteristics of the solar corona can be analyzed only during solar eclipses. The solar corona is the breeding ground for many of the magnetic disturbances in the earth's atmosphere.

capability of any ground telescope and permitted a detailed height analysis of the chromosphere. Thus, after their earlier disappointments the Sacramento Peak scientists found they had been so successful that an enormous reduction problem was created, and analysis of the data may easily continue for a decade.\*

**STATISTICAL CHARACTERISTICS OF FLARES:** During the period the important characteristics of 11,000 flares recorded by the Observatory (600 were recorded during 1961-1962) were listed on punched cards, and fed into a large computer in an effort to determine statistical characteristics. A vexing problem connected with this program was that of designating flare size for flares viewed near the solar limb. On the assumption that the frequency distribution of various flare areas was the same in all longitudes (with respect to the sun's central meridian), the foreshortening near the limb could be determined fairly directly and an estimate made of the ratio of the thickness to the horizontal extent. It was found that the small flares were approximately hemispherical, and the foreshortening was fairly regular. Large flares, on the other hand, were so irregular and varied in their geometrical shape so widely, that it was impossible to apply a foreshortening factor that had much meaning in any single instance. This was very unfortunate since the large flares which produce the most dangerous proton showers were unlikely to be near the western limb, and uncertainties as to their actual sizes were troublesome in the study of flare characteristics relevant to proton emission.

Other aspects of the computer study centered on the relationship between

\* A total solar eclipse in Italy in February 1961 was observed by Radio Astronomy Branch personnel. See discussion below.

flare sizes, the shapes of the light curves, total life times, the tendency to have "sympathetic flares" (i.e., a repeat performance in the same location within a few hours), and the probability of emission of a fog of obscuring matter which hides the surrounding details of the active center.

**PROMINENCE FILAMENTS:** In related research the Sacramento Peak scientists also undertook an analysis of the very fine prominence filaments recorded on direct photographs taken under conditions of best seeing. The diameters of these solar filaments, less than the resolving power of the instrument ( $0.45''$ ), maintain their radiation over periods of hours. The question arose, where did the filament energy come from? Since the filament was immersed in the corona at  $10^6$  degrees Kelvin, it was proposed that the energy was provided by straightforward heat conduction into the relatively cold interior of the filament (about  $10^4$  degrees). Given corona and prominences of known density and temperature, it was possible to calculate the run of temperature and its gradient from the central core of the filament outward. According to the analysis, filaments 1000 kilometers in diameter (fairly typical) could be expected if the field strength was of the order or  $10^{-4}$  gauss, and the problem became to determine why the field was so feeble, rather than why it was surprisingly large. The researchers' conclusion was that the energy in the prominence could certainly and reasonably be provided by conduction from the corona, and filaments of any observed size could be expected. This theory appeared to be the only one that could satisfactorily account for the observations, although it strained other theories about the magnetic field strengths in coronal space, which had been generally assumed to be of the order of 1 gauss rather than  $10^{-4}$ .



Solar flares extend outside from the chromosphere to distances of 15,000 to 100,000 miles. The chromosphere itself shown beneath the flare is marked by a number of small irregular prominences known as spicules.

#### THE INSTRUMENT DEVELOPMENT

**PROGRAM:** As was noted earlier, the Sacramento Peak astronomers had managed to achieve a remarkable record in its solar patrol program, using a cluster of small telescopes and coronagraphs accumulated and constantly improved over the years. This equipment included:

1. A small flare patrol telescope of 6 centimeter aperture, which forms a 15 mm image of the sun on the film gate of a stop motion cine camera through a birefringent filter. The filter has a 0.65 angstrom pass band tuned to the hydrogen alpha line, an arrangement exactly analogous to a tuned radio. It transmits only the light of the hydrogen in the upper layer of the solar atmosphere. Since the camera takes one exposure every two minutes during the daylight hours, it provides a record of the occurrence and development of every flare within that period. The system also shows many other types of activity on the solar disk, and has been an invaluable

auxiliary for other kinds of observations at the Sacramento Peak Observatory and other observatories.

2. A 10 centimeter coronagraph and Littrow spectrograph combination for photographing at frequent intervals the coronal spectrum at all position angles around the solar limb. The spectro-coronagraph records the variations in the intensities of coronal lines as a function of position angle and time.

3. A 15 centimeter coronagraph of exceptional quality, imaging an artificially eclipsed image of the solar limb through a birefringent filter on a cine camera. The filter may be tuned either for the hydrogen alpha line or the 5303 line of the corona (Fe 14). The assembly produces motion pictures of the most interesting prominences or coronal activity, at rates of from 10 to  $\frac{1}{2}$  frames per minute. When projected, these movies show the activity greatly accelerated and provide researchers a most sensitive means for detecting subtle changes in solar limb activity.

4. A simple 15 centimeter white-light telescope which projects a 20 centimeter image of the sun on a drawing board, to provide observers with a working chart of the sunspots on the disk.

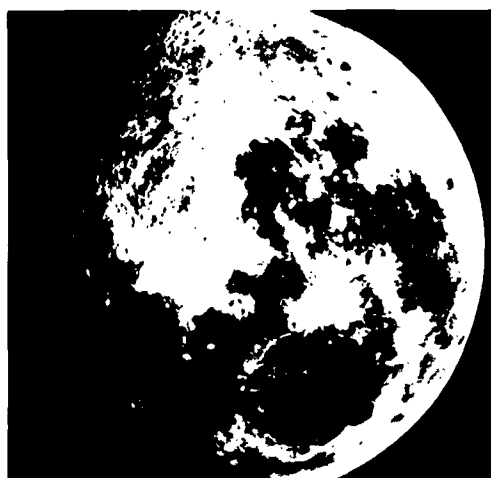
While the above equipment had proved highly useful, it had become clear to Sacramento Peak personnel that new and more refined instrumentation was required for better observations. Accordingly, during the period an extensive optical and mechanical instrumentation development program was pursued in-house and with contractor assistance. It involved the construction of a new 9-inch coronagraph and a 16-inch simple telescope (completed in December 1961); design and construction of a five-channel photon counter capable of counting  $10^8$  photoelectrons per second, which should yield better data on solar profiles between center and limb of the solar image

(scheduled for delivery in August 1962); modification of the 16-inch coronagraph to provide better definition of solar spicules, prominence filaments, etc.; and development of a new universal spectrograph, field magnetometer, and related new patrol equipment.

An important element in the advanced equipment program, which was aimed at obtaining more detailed observations of the solar disk and expanding the flare prediction project, centered on acquisition of a vacuum telescope. Construction of this new Sacramento Peak instrument was tentatively approved by the Air Force during the period. Planned for a 1964 construction start, this major project will consist of a tower-mounted, mirror-fed vacuum telescope. The tower, 128 ft. tall, will contain an optical tube extending into a vertical shaft 200 ft. below ground level. Light gathered by a coelostat with an aperture of 30 inches will be transmitted to the optical instruments at ground level, by a system of mirrors and lenses mounted inside the 328 ft. vacuum tube. This unique instrument, together with associated facilities, was expected to greatly enhance the Observatory's prediction capability during the next solar flare maximum (1966-1971).

#### LUNAR AND PLANETARY RESEARCH

A research program to determine the composition of lunar and planetary surfaces and planetary atmospheres was another aspect of the AFCRL space research effort pursued during 1961-1962. This investigation, conducted by the Lunar Planetary Exploration Branch, was aimed at obtaining information on the chemical and mineralogical composition of the moon and planets, and their atmospheres, topography, temperature, electrical and thermal conductivity, radioactivity, density, etc. Rocket and balloon-borne instrumentation and ex-



The lunar environment is of great interest to the Air Force. AFCRL is conducting several programs designed to learn more of lunar temperatures and the characteristics of the lunar surface.

periments were the techniques used, or scheduled for use, to obtain indirect measurements of chemical and mineralogical composition through X-ray, ultraviolet, visible and infrared spectroscopy. Important laboratory and theoretical studies complemented the experimental program.

**ROCKET-BORNE RESEARCH:** The possibility that X-ray flux from the moon might be sufficiently high for analysis from the vicinity of the earth was first suggested to AFCRL researchers in September 1959.\* Theoretically, the wave lengths of secondary X-rays emitted by lunar surface materials, as a result of bombardment by solar radiations, should be characteristic of the elements involved. Thus it appeared that spectral analysis of the region between 2 and 30 Angstroms would reveal the presence and relative concentrations of most of the elements on the moon's surface, including all those below atomic number 20, as well as most of the heavy metals such as iron, copper and nickel.

The first actual AFCRL experiment to obtain X-ray data from the lunar surface was conducted in September 1960 but the rocket misfired. The second attempt on 24 October 1961 was a partial success. An X-ray counter, flown aboard an Aerobee rocket launched from the White Sands Missile Range, for the first time detected lunar X-rays. Although there was a partial failure of equipment due to retention of two out of three of the nose cone doors, examination of the X-ray flux that was recorded indicated it might be possible to determine the composition of the lunar surface by spectral analysis. On 18 June 1962 a third experiment was successfully flown aboard an Aerobee rocket at White

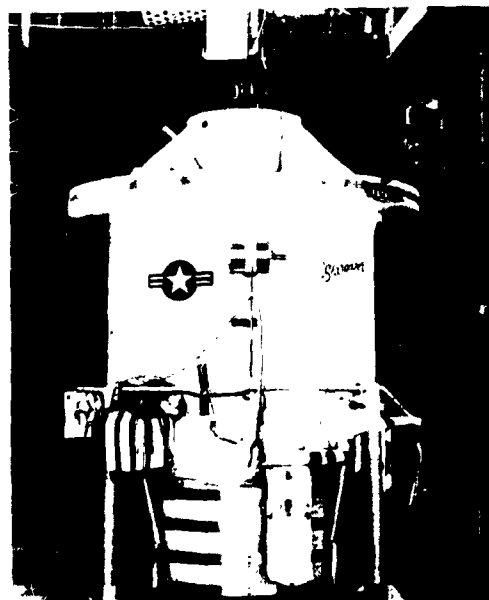
\* By the American Science & Engineering Corp. of Cambridge, Mass.

Sands, and this time good data was obtained on total lunar X-ray intensities, which were measured by means of three specially developed large window Geiger counters. At the close of the period, data from the third flight were being analyzed, and the scientists were planning additional flights in May and October 1963.

In connection with the above work, an AFCRL contractor has developed a coaxial linear pointer to be carried on future Aerobee flights to point the instrument toward the moon regardless of the roll, pitch or yaw of the rocket. In addition to its use with an X-ray spectrometer, the pointer is to be used with an ultraviolet camera to obtain photographs of the moon in various regions of the ultraviolet spectrum. Use of the system, which is scheduled on a first flight in January 1963, should provide information not only on the gross spectral response of the moon, but also on the variations across the lunar surface. Eventually, AFCRL plans to use an ultraviolet spectrometer to examine planetary atmospheres—if the difficult problem of constructing a rocket pointer to track objects as dim as Mars and Venus can be solved. Such a system should provide vital data concerning the amount of hydrogen, oxygen and nitrogen in those planetary atmospheres.

**BALLOON-BORNE RESEARCH:** The fact that modern balloons are capable of rising above 99 percent of the infrared absorbing constituents of the earth's atmosphere was the basis of an unusual AFCRL balloon astronomy development program pursued during 1961-1962.\* This program centered on three balloon-borne platforms, two unmanned and one manned. The major objective of the manned balloon system, designated

\* See also Chapter X on Aerospace Sounding Technology.



The two-man gondola to be used in the Stargazer project, was designed to send men to extreme altitudes in a balloon for observation by optical telescope of the moon, Venus and other planets.

Project Star Gazer, is to test the feasibility of manned balloon astronomy. A 3600 pound gondola was developed to carry an electro-optical tracking device and automatic stabilization system, which will allow telescopic observation of stars in the relatively scintillation-free altitudes of approximately 86,000 feet. Observers within the gondola will be able to override the automatic tracking device, if necessary, and operate manually.

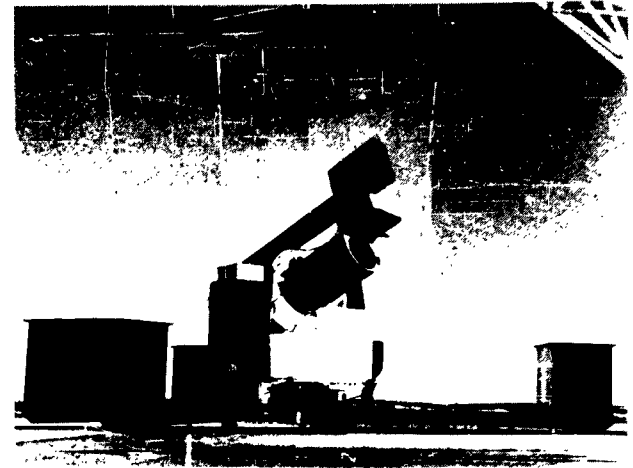
In March 1962 the first successful test of the Star Gazer balloon system was accomplished with a launch from Chico, California. Several subsequent flights, however, revealed the balloon did not have sufficient reliability for the weight carried. Pending procurements of a new balloon manufactured from a stronger, laminated scrim material, further un-

manned flights were re-scheduled for the September-October 1962 period. A two-man crew will man the flight planned for December 1962.

The second AFCRL balloon astronomy effort, Project Ballast, involves an unmanned, completely automatic system. During the initial flights set to begin in August 1962 the primary scientific objectives will be to search for evidence of water vapor, carbon dioxide and other gases in the atmosphere of Venus. The temperature and heat balance of the planet also will be studied, as well as the infrared spectrum of reflected solar radiation. The system includes a coarse control to seek and lock onto the sun, and to track it to within approximately 5 seconds of arc through a fine control, and then to point the telescope towards Venus via a programmed offset.

The third balloon astronomy program, Project Sky Top, also is an unmanned completely automatic system. Spectroscopic techniques will be used to detect and determine the approximate concentrations of water vapor, carbon dioxide and other gases in the planetary atmospheres of Mars and Venus. Using radiometry, an effort also will be made to determine planetary temperatures and, more importantly, the distribution of the moon's nighttime temperatures. Such lunar temperatures are now known only to within approximately 50°C. The Sky Top program is expected to improve the measurements to within 5 degrees or less, which will not only aid the determination of the physical characteristics of lunar surface materials but also may detect any "hot spots" on the moon. The first Sky Top flight will carry a Block interferometer to look at reflected light from Venus in the 0.7 to 3 micron region.

**LABORATORY AND THEORETICAL STUDIES:** In a related project during the period an AFCRL simulation chamber was constructed to enable the scientists



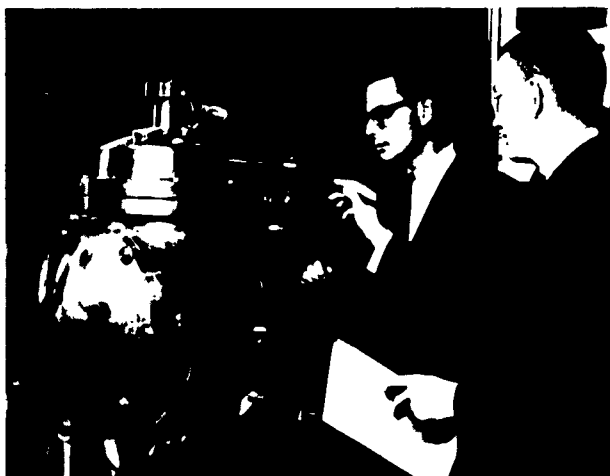
Transporting telescopes by balloon to extreme altitudes is an economical means for placing a telescope well above all but a fraction of the atmosphere. Shown here is one of the early AFCRL telescopes sent aloft for observing the moon and various planets.

to measure thermal conductivity, spectral response and other physical characteristics of probable lunar materials in a simulated lunar environment. The chamber is capable of attaining a vacuum of  $10^{-6}$  mm of mercury, and bathing a sample in a close approximation of solar particulate and electromagnetic radiation. The laboratory spectra of lunar and planetary surface materials and gases in their respective simulated environments are to be compared with spectral data obtained from balloon and rocket experiments. In addition, after field studies in the ultraviolet and infrared have more nearly determined the gross composition of planetary atmospheres (the only gas positively identified in the atmosphere of Mars and Venus is carbon dioxide), model atmospheric studies are planned. The resulting knowledge of atmospheric density, pressure and ionization profiles is expected to be extremely useful for the design and

operation of rocket vehicles within the planetary atmospheres.

An important phase of the lunar planetary program involved theoretical studies aimed at the integration of data accumulated through various field spectroscopic studies with laboratory research. During the period a program of statistical studies, utilizing available photography, was conducted and an effort made to predict the microtopography and surface characteristics of different areas of the moon, based on statistical analysis of the coarser features visible on photographs. These theoretical studies were concerned with evolving new and better theories of the origin, history and utilization of the moon and planets and their surface features.

In 1961 a study was published on the "Location of a Lunar Base" and the geological problems involved, and on use of lunar natural resources. In addition, in a paper on the "State of Lunar Dust,"



A new AFCRL facility is this lunar environment chamber where the atmospheric and radiation conditions found on the surface of the moon will be simulated. The chamber will be placed in operation in October 1962.

AFCRL researches theorized that the moon dust was thin, compact and unyielding — rather than being loose as suggested by other investigators. According to this theory, the almost perfect vacuum on the moon would not permit dust particles to be slightly separated by air molecules, as on Earth, and this would result in a tightly-packed firm surface for space landing purposes. In addition, molecules of lunar surface material sputtered off nearby grains by the impact of solar protons and neutrons would tend to act as a cementing plaster on the dust. The AFCRL researchers have suggested experimental work in the environmental chamber which, when combined with temperature observations of the lunar surface made with the Sky Top balloon-borne telescope, should verify this theory.

**GROUND-BASED SPECTROSCOPIC AND PHOTO STUDIES:** A program of ground-based contractor spectroscopic and photographic studies in the visible region of the spectrum also formed a part of the AFCRL lunar/planetary research program. Various studies of the moon and planets were conducted by observatories in the United States and France. In early 1962 an AFCRL contractor published Volume II of the *Lunar Atlas*, based on the best available photography of the moon and showing both orthographic grids and longitude-latitude coordinates for the lunar surface. The first volume of the *Atlas* was published in 1960. During the period another contractor was engaged in collecting the best available Mars photographs obtained from observatories all over the world.

Because existing photography has relatively poor resolution of lunar and planetary surface features, AFCRL supported programs to obtain improved photographs from ground-based observatories. Thus, for example, a new

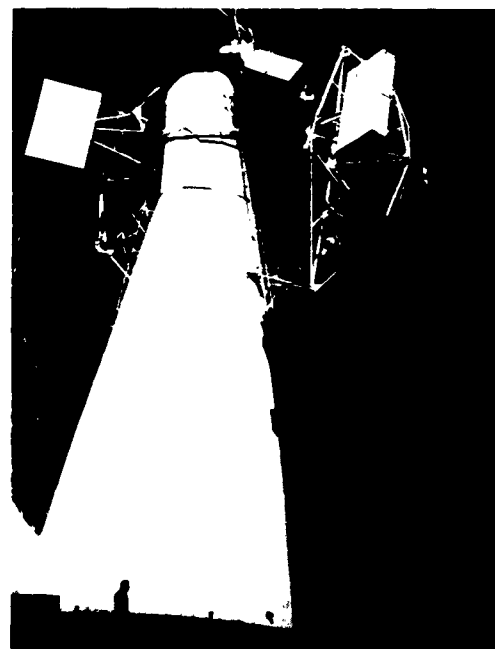


The temperature and surface features of Mars (photographed here in red light) is another area of AFCRL interest.

43 inch reflecting telescope was acquired for Pic du Midi Observatory in France, which, at an altitude of 9300 feet and because of its location, has some of the best "seeing" in the world. The new telescope became operational in April 1962 and should be able to obtain superior photographs of the moon and planets. Another approach to the problem of obtaining better resolutions was through use of electro-optical techniques of image intensification. Studies in that area were underway at the end of the period.

Another project still in the planning stages involved construction of an AFCRL Planetary Observatory in southern New Mexico, to serve as a complete center for astronomical studies with emphasis on the planets.

For several years the new techniques of radio astronomy have been invoked by the Air Force Cambridge Research Laboratories to obtain new fundamental knowledge of the electromagnetic properties of the earth's outer atmosphere, the planets, the interplanetary medium and the solar corona. For this experimental work, AFCRL's Radio Astronomy Branch has employed an 84-foot radio telescope and log periodic antennas at Sagamore Hill near Hamilton, Massachusetts, and a 28-foot antenna at Reservoir Hill. The construction of a larger 150-foot steerable parabolic antenna, which began in June 1961, was expected to greatly enhance in-house capabilities on completion in 1963. The AFCRL radio astronomy program encompasses studies of planetary radiation



The 84-foot radio telescope at Sagamore Hill is used for Air Force research relating to communications and detection.



of several types (black body, synchrotron and burst) to determine the electro-magnetic reflection and emission properties of planetary atmospheres; investigations of the modulation processes of solar bursts; and hydrogen line research on radiation processes from extra galactic sources.

**PROPAGATION STUDIES USING RADIO ASTRONOMY TECHNIQUES:** During 1961-1962, utilizing signals from radio stars and the sun, and the 84-foot antenna and the log periodic antennas at Sagamore Hill, AFCRL scientists conducted multi-frequency studies at both ionospheric and tropospheric absorption, refraction and scintillation. During periods of intense magnetic disturbances, various special effects were recorded. The small scale high electron density structure of aurora blobs produced 5 percent scintillation level even at 1300 Mcps. At 226 Mcps Cynus A and Cassiopeia A signals showed 100 percent scintillations with periods of 2 to 3 seconds during periods of intense auroral activity.

The above data, recorded off the 84-foot telescope, showed that the scintillation index varied directly with some power of the frequency in the radio spectrum below 225 Mc instead of the normal inverse frequency law. This inversion effect was strongly localized and temporal. During magnetic conditions, the alignment along the earth's magnetic field produced a diffraction-multiple scattering pattern which yielded non-coherent scintillation signals across the radio telescope aperture, indicating a small-scale ground pattern. These atmospheric propagation studies, which were continuing at the close of the period, were important in determining coherence in the frequency range 20 to 1000 Mcps across large apertures during magnetic storms. Due to the partial coherence effect, decrease was noted of signal level up to 2 db at 62 Mcps.

**SATELLITE PROPAGATION DATA:** Satellites provide a convenient signal to study propagation effects through the atmosphere. During the period a series of continuous earth satellite recordings were made on frequencies from 20 to 150 Mcps, in cooperation with six European stations which also made coordinated amplitude and doppler recordings. In some cases, instrumentation was furnished the foreign research laboratories by AFCRL. The European net, besides being useful for propagation studies, provided an excellent quick reaction tracking capability on Soviet satellites. During 1961 the NATO Scientific Advisory Committee authorized a broad program of joint satellite studies by the six European stations and AFCRL. The new program involves fast recording techniques and common methods of taking and reducing data. The Radio Astronomy Branch served as coordinator for the above program, obtaining orbital predictions, naming the periods of interest and disseminating the data. Several meetings were held in Europe at which raw records of the several members were compared for Doppler irregularities, scintillation observations, auroral effects, and satellite transmission details. Publication of results on triangulation of scintillation clouds also was accomplished.

The continuing joint satellite program will emphasize research into the total electron content of the ionosphere (and its variations) up to satellite height. Investigations also will be conducted into large and small scale patches of irregularities in the ionosphere, absorption of radio waves penetrating the ionosphere, and propagation paths from the satellites.

**SOLAR INVESTIGATIONS:** On 15 February 1961, in cooperation with Italian astronomers, Radio Astronomy Branch scientists observed a total eclipse at

Florence, Italy, which was near the center of totality. As the moon moved across the Solar disk, the still uneclipsed solar energy was measured as a function of time with the following equipment: a 5-meter equatorially mounted antenna on which a 1270 Mcps radiometer was used; a 4-foot equatorially mounted antenna, driven simultaneously with a 5-meter dish, on which a 9710 Mcps radiometer was used; and a 6-foot equatorially mounted dish with a radiometer which employed a timesharing principle.

The sun was very quiet during the period. The eclipse showed some anomalies, however, due to solar source activity. After corrections were made for absorption, refraction and the lunar temperature, the residual energy existing during totality (which occurred at an elevation angle of  $12.65^\circ$ ) was found to be 6.6 percent at 9710 Mcps. Preliminary inspection of data at 1270 Mcps revealed a high residual signal at totality (24.6 percent) and an interval of about 17 minutes between fourth contact and the time at which the eclipse curve flattened out. The radio eclipse at this frequency was only 93.5 percent complete at fourth contact. These data were used to determine the radio diameter of the sun and the height above the photosphere of the enhanced regions at 1270 and 9710 Mcps.

The eclipse measurements also were analyzed by comparing them with a solar contour map made at Hamilton using the 84-foot radio telescope and a 3-cm pencil beam, and also with 1300 Mcps contour maps furnished by an Australian agency. At the close of the period, looking forward to the 20 July 1963 eclipse, plans were being made to locate an AFCRL observing site in the Bangor, Maine area.

**MODULATION STRUCTURE OF SOLAR BURSTS:** In related work, AFCRL scientists conducted preliminary experiments



This view shows AFCRL's new 150-foot radio telescope in relation to the existing 84-foot dish. With the completion of the new telescope, AFCRL will operate one of the finest radio astronomy facilities in the country.

on a possible technique for studying the mechanisms of solar radio radiation by recording at discrete frequencies the modulation structure of solar bursts and the quiet-sun radio noises. Observations were made at 220, 400 and 3000 Mcps, using the 84-foot telescope. Subsequently the magnetic tape records (made to observe direct-current to 600 cps fluctuations) were analyzed over the frequency range 5 to 550 cps to detect enhancements or absorption in that range.

The high solar radio activity of 11 August 1960 earlier had provided the scientists an opportunity to record type II, III and IV events. The modulation-envelope spectra of all types of bursts, when normalized against noise samples, showed definite structure. The high-frequency end of the very low frequency band was accentuated on all three frequency channels. Type II and type IV bursts were characterized by marked attenuation over certain very low frequency bands. These spectral regions were distributed throughout the analyzed band and had a maximum bandwidth of approximately 60 cps. The

spectrum of the envelope of an isolated burst of 400 megacycles showed a sharp and fast development of structure around two narrow very low frequency bands. Subsequently, a more detailed study of the modulation spectra over a wider band was undertaken, in an effort to determine whether different types of solar bursts were associated with distinct patterns of audio modulation.

To obtain additional solar signal data, during a transit of Mercury across the sun's disk on 7 November 1961, AFCRL scientists utilized the 84-foot telescope at 3 cm. Although the antenna efficiency is low at that operating frequency, very good angular resolution (about 7 minutes of arc) was obtained. The possibility of noting an eclipsing of the solar energy by Mercury was remote because of the ratio of approximately 160 to 1 between the diameters of the sun and the planet. During the transit, however, the scientists were able to make a contour map of the solar spot region which produced the three cosmic ray flares of November 1960.



To be erected in the fall of 1962 is this 150-foot parabolic dish. Used in conjunction with the nearby 84-foot radio telescope, the telescopes will provide AFCRL with an extremely sensitive interferometer.

**LUNAR REFLECTION/EMISSION MEASUREMENTS:** In cooperation with Jodrell Bank astronomers, work was done during the period on trans-Atlantic moon reflections. The 84-foot dish was used to receive on two orthogonal antennas the moon reflections of linearly polarized signals transmitted by the Jodrell Bank 250-foot telescope on 100 and 99.4 Mcps frequencies. These observations were used to measure the total integrated electron density for the two paths by the Faraday polarization-rotation method.

Earlier, a 99.4 Mcps bistatic moon-reflection experiment was conducted in November 1960, a period of increased solar flare activity. Although regular Faraday fading was observed on the mornings of 11, 12, and 14 November 1960, extremely fast changes in the rate of Faraday rotation of the plane of polarization of the signal received was noted on 13 November. The path from the moon to the 84-foot antenna on Sagamore Hill went through the southern edge of an aurora. AFCRL scientists advanced the hypothesis that the ordinary and extraordinary waves constituting the received signals encountered aurorally produced small-scale irregularities with high draft velocities, which were responsible for the phase variations.

In somewhat related work, during a three-day period that included the lunar eclipse of 25 August 1961, a brief moon-study program was undertaken to supplement and substantiate data obtained during the lunar eclipse of 13 March 1960. The principal objective of the program was to study simultaneously obtained records of the lunar thermal emissions at 1200 and 3100 Mc in order to determine whether or not any perceptible change could be noted at either frequency during the eclipse. The differential antenna temperature of the moon above the ambient sky temperatures was determined accurately and used by

means of a simple straightforward method to obtain the average disc temperature. No change in lunar temperature was measured during either eclipse.

Simultaneous recordings, displayed on a dual-channel recorder, were made possible by the use of a multi-frequency Jasik antenna feed system with the same polarization for each frequency. In the 3100-Mc system, the receiver used three stages of travelling-wave-tube amplifiers in series, similar to that used in the March 1960 instrumentation. The 1300-Mc receiver system used earlier was, on the other hand, changed to a superheterodyne configuration because of the radar interference encountered at this location and frequency when wide-band amplifiers were used. Whenever possible, antenna cable losses were reduced below the value of the March 1960 system. The equipment was operated in a well-controlled temperature environment.

**HYDROGEN LINE STUDIES:** Observations of the 21-centimeter line radiation from extra-galactic nebulae also were conducted, using the 60-foot radio telescope at Harvard Observatory. The galaxies under investigation are close enough to the Earth to allow moderately detailed study of the neutral hydrogen distribution and motion. These studies revealed a large gaseous envelope of hydrogen around each galaxy. In addition, they permitted a determination of the mass of three systems and the ratio of hydrogen to total mass in each, a quantity which was considered to be probably related to the type and age of the galaxy. With the installation of a hydrogen-line receiver at the Hamilton site scheduled for late 1962, related studies were being planned to emphasize objects within the Milky Way, which can be studied in great detail with the increased resolution of the 84-foot and 150-foot antennas.



The Dyna-Soar pilot, reentering the atmosphere at a relatively shallow angle, could be cut off from outside communications for as long as 30 minutes if techniques for penetrating the plasma sheath are not developed.



Plasma physics—the study of the properties and effects of the gaseous state of matter—is one of the newer areas of scientific inquiry. A plasma is a neutral gas made up of free electrons and positive ions and thus influences electromagnetic radiation in various ways. The gas, in turn, can be manipulated by certain electric and magnetic mechanisms and by means of those mechanisms can be made to do useful work. It has particular importance for aerospace activities since vehicles travel through the earth's ionization layers, create ionization trails in their exhaust, and may also use plasmas for propulsion. Air Force operations directly affected by plasma phenomena include communications, surveillance, detection and identification, since both orbiting and re-entering bodies generate ionized layers which have a marked effect on the radar cross-section and on telemetering signals to and from the vehicle. Knowledge of plasma physics is important for the design of electronic components and techniques to generate electromagnetic radiation in new frequencies and to detect EM signals.

In seeking to obtain a deeper understanding of the gaseous state of matter, the Air Force Cambridge Research Laboratories were able to draw upon the multidisciplinary talents and facilities of five in-house groups, including the Electromagnetic Radiation Laboratory, Electronic Material Sciences Laboratory, Detection Physics Laboratory, Optical Physics Laboratory, and Ionospheric Physics Laboratory. During 1961-1962 these AFCRL groups were engaged in a number of experimental and theoretical

research programs in plasma physics, including investigations of the effects of magnetic fields on ionized gases and electromagnetic emissions from shock-excited plasmas, and studies of exploding wire phenomenon, high temperature plasmas and the specific problem of communications blackouts caused by the ionized sheaths formed about re-entry vehicles.

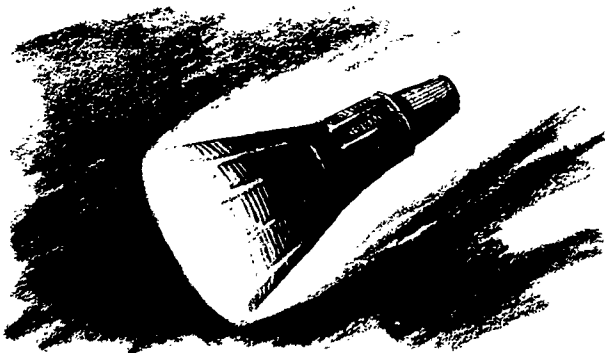
#### **COMMUNICATION BLACKOUTS AND THE PLASMA SHEATH**

For several years the Electromagnetic Radiation Laboratory has been studying the problem of re-entry ionization effects on radio communications and signal transmission from a re-entry vehicle. The investigation encompasses: (a) theoretical analyses of the properties of the plasma sheath and its interaction with radio waves; (b) laboratory studies in plasma simulation; (c) wind tunnel and shock tunnel experiments on re-entry communications; and (d) field tests of re-entry phenomena, using specially instrumented rockets.

The problem of the plasma sheath centers on the fact that as a vehicle re-enters the Earth's atmosphere at hyper-

sonic velocities, a layer of hot ionized gases forms which severely degrades the transmission and reception of radio signals. The surrounding layer of ionized gas produces such effects as signal attenuation, reflection, refraction, phase shift, spurious modulation, and loss of coherence. This situation makes continuous and reliable communications with re-entry bodies impossible, and it is common to have communications blacked out for a considerable distance along terminal trajectories. For example, during the Glenn orbital flight of 20 February 1962, and the Carpenter flight of 24 May 1962, communication blackouts occurred and lasted for several minutes on both occasions.

In the case of a manned vehicle such as the Air Force X-20 (Dyna-Soar), the seriousness of the problem becomes much more acute. The planned re-entry trajectory of the Dyna-Soar is much shallower than those of the Project Mercury capsules, and a considerable length of time will be spent by the pilot in the upper atmosphere where blackout occurs. Loss of communications for periods up to tens of minutes or more are expected during the most critical portion of the vehicle's flight regime.



The plasma sheath which surrounded the first two manned capsules upon reentry isolated the occupants from outside communication for more than four minutes.

#### **RE-ENTRY COMMUNICATION FIELD**

**TESTS:** It was to resolve the above problem that a flight test program, originally proposed by AFCRL in 1958, was formally established in 1961. Its basic purpose was to investigate the proper radio frequencies for possible ion sheath penetration, and to assist in evolving techniques for eliminating the radio blackout during re-entry. The program called for flying an instrumented Blue Scout re-entry vehicle in a shallow trajectory over the Atlantic Missile Range in order to:

1. Measure signal attenuation, antenna pattern distortion and antenna impedance mismatch at VHF, UHF, and

microwave frequencies during a re-entry trajectory and compare the data with theoretical predictions.

2. Compare tests of VHF (220 Mcps) versus UHF (2250 Mcps) telemetry under re-entry conditions.

3. Measure radiation frequency noise generated by the plasma sheath by means of a vehicular microwave radiometer.

4. Develop measurement techniques and procedures, such as means for determining characteristics of the shock-ionized flow fields and the required nose cone altitude and trajectory data for use on future re-entry flight tests.

The Blue Scout flight profile called for the vehicle to reach a maximum altitude of about 150 miles. On 12 April 1962 the first of the AFCRL re-entry communication experiments was launched from Cape Canaveral. Unfortunately, the second stage of the rocket failed to



Drawing shows separation of third stage of Blue Scout vehicle from reentry payload. The nose cone contains an AFCRL reentry communication experiment designed to measure radio signal attenuation through the plasma sheath.

ignite, apparently because of a faulty pressure switch in the first stage engine. The payload itself functioned perfectly before it plunged prematurely into the sea; data was received by ground receiver stations at Melbourne Beach, Grand Bahama Island, and San Salvador.

Since the Cape Canaveral test could not be repeated because in the future Blue Scout vehicles will not be launched from that site, AFCRL scientists were forced to make alternate arrangements. At the close of the period plans were being made to continue the re-entry communications test program, using Trail Blazer II vehicles to be launched from NASA's Wallops Island facility. Three vehicles were requested for this program with the first launch scheduled for June 1963.

**EFFECTS ON ROCKET ANTENNAS:** In connection with the plasma sheath effects, the Ionospheric Physics Laboratory also developed several experimental techniques of direct probing of the ionosphere for the measurement of electron density, ion density, ion temperature and electron velocity distribution. An experiment combining an antenna impedance probe and a retarding potential probe was flown on two Aerobee 150 rockets and two interesting results were obtained with respect to expected and unexpected plasma effects.

The first result was the anticipated effect of the ion sheath on the antenna, impedance experiment. In order to remove the ion sheath around the antenna, it was necessary to bring the antenna to space potential. In the experiment this was accomplished by the application of a dc voltage varying linearly from 0 to 4 volts between the rocket body and the dipole antenna. Langmuir currents obtained demonstrated the effect of the change in the ion sheath. A comparison with the potential of the rocket with respect to space obtained



from the retarding potential measurement indicated a transition from a positive ion sheath to a negative one.

Examination of the electron densities from 60 to 150 kilometers derived from the reactance data did not show any obvious effects of the alteration of the ion sheath by the dc voltage or of the earth's magnetic field. This data would seem to indicate that with an antenna potential of about  $\pm 2$  volts relative to space and an antenna of measurable radiation efficiency, the effect of the ion sheath on radio frequency impedance was negligible. The fact that there was no correlation of the electron density fluctuations and the spin rate of the rocket could be reasonably explained if the rocket spins around a nearly vertical axis so that the antenna is always in an approximately transverse position to the magnetic field.

It was interesting to note that the AFCRL scientists found in their results a strong dependence on the spin position



Partially assembled nose cone for Blue Scout reentry communication experiment is shown. External configuration is a hemisphere-cylinder-flange combination of twenty inches diameter. The copper hemispherical heat sink can be seen in the foreground. Antenna radiators are located on side of vehicle.

during the short time of descent where the rocket tipped over when entering the dense atmosphere at about 100 kilometers. A preliminary analysis of the data indicated a change of the measured electron density with antenna direction by almost a factor of two. The aspect data available, however, did not permit discrimination among the direction of the magnetic field, the sun and the flight trajectory.

The second result obtained from the experiment was unanticipated and was much more drastic. On rocket ascent up to 150 kilometers, the electron densities derived were reasonable and comparable to those obtained from the high frequency ionospheric recorder. However, from 160 kilometers the electron densities decreased very rapidly until at peak altitude of 265 kilometers the values were the same as those obtained at 95 kilometers. From 265 to 160 kilometers on rocket descent, the electron densities required a correction by a factor of 6 to be compared with ionogram results. Passing a rapid transition from 100 Km down the ascent and descent data were the same.

The interpretation of these data was that the rocket fuel valves, which were still open after burnout, continued to let some residual propellants escape throughout the flight. When the diffusion velocity of the propellant reached a value greater than the rocket velocity, the ambient electron density around the antennas was reduced by an attachment process. The position ion measurements with the retarding potential probe gave values in accordance with ionogram data. This was considered evidence that there was an attachment process involved. The propellants for an Aerobee rocket consist of a mixture of aniline and furfural alcohol as the fuel and red fuming nitric acid as the oxidizer. The aspect data indicated that between 112

and 109 kilometers the rocket, which was descending tail first, nosed over. The antennas, which are in the nose cone of the rocket, then came out of the environment disturbed by the leaking propellant. At the close of the period the contribution of this factor to plasma sheath effects on antennas was being further evaluated by the Ionospheric Physics Laboratory.\*

**THEORETICAL AND LABORATORY STUDIES:** While the above results were being studied, the Electromagnetic Radiation Laboratory was engaged in related work to simulate the plasma sheath and its effects. Thus, the electrical properties of the plasma—that is, its dielectric constant of less than unity and its loss characteristics—were reproduced successfully by the use of artificial dielectrics made of wire grids and also of parallel plate media. These techniques are currently being applied to antenna radiation problems involving non-isotropic or non-homogenous plasmas in complex geometries. In addition, several contractors began model tests of nose cones in both shock tunnels and high density wind tunnels.

Another in-house approach by the Electromagnetic Radiation Laboratory made use of commercial fluorescent light tubes as the source of the plasmas. The technique had the advantage of economy, avoiding expensive vacuum equipment, and also had versatility in that non-homogenous plasmas could be produced in a controlled fashion by varying the current to each tube. The changes in radiation pattern caused by variable radio frequency power level also could be studied by the technique for non-linear effects.

During the period AFCRL theoretical

studies demonstrated that the plasma sheath on re-entry vehicles could generate sufficient radio frequency noise (through radiation from the ionized gases) to influence the performance of high-sensitivity vehicular receivers. It appeared possible that measurement of this noise could be used as a diagnostic tool to determine the plasma and collision frequencies of the sheath.

To investigate those properties Electromagnetic Radiation Laboratory scientists designed a highly sensitive radiometer for the test vehicles, consisting of a miniature transistorized crystal video receiver. Basically, the radiometer is of the Dicke type in which the noise generated by the plasma is compared to a reference noise source within the receiver. The comparison is made by switching the input of the radiometer from the receiving antenna to the internal noise reference at a rapid rate. This procedure causes the incoming noise signal to be modulated at the switching frequency, then amplified in a narrow band amplifier. The output of the amplifier is fed to a coherent detector which produces a dc voltage at its output proportional to the difference in levels between the noise and the reference. This output is converted to the proper form for transmission to a ground station over a telemetry link.

This AFCRL radiometer was designed to be used over a wide range of frequencies by changing only the radio frequency components. Initially, the equipment was to be integrated by Optical Physics Laboratory personnel into the warhead of an Atlas missile for re-entry diagnostic measurements. It also was planned to develop more sophisticated microwave radiometers such as swept frequency and incremental-frequency models for inclusion in future re-entry payloads.

In related theoretical work the

\* Other work by the Ionospheric Physics Laboratory in plasma physics is reported elsewhere in this chapter.

Electromagnetic Radiation Laboratory sought to calculate the expected flow fields about the re-entry vehicles, and to predict antenna pattern distortion. Initially attention was directed to plasma-covered antennas radiating into free space. However, subsequent work indicated that an applied magnetic field might improve communications. On the premise that a static field would improve propagation, the scientists began an intensive study of pattern distortion due to an anisotropic plasma. Radiation patterns were calculated for a plasma-covered slot in a cylinder and ground plane. In each problem the antenna was covered by a uniform plasma layer with and without an applied magnetic field. It appeared that an annular slot with an applied normal field could be used to transmit energy when the plasma would otherwise be opaque. At the end of June 1962 an experiment to verify the above theoretical considerations was underway.

In connection with the attenuation and distortion of signals by the plasma sheath, the interaction of the electrons with the transmitted waves were determined by the distribution of electrons in the medium. Since calculations of the ionized-particle profiles required knowledge of the aerothermodynamic properties of the flow field, any data obtained also were pertinent to studies of real gas hypersonic flow. The desirability of having a common factor for comparing data with that obtained in analogous studies in missile aerodynamics led AFCRL scientists to choose the hemisphere cylinder as the configuration for investigation. Theoretical calculations were made for an altitude of 200,000 feet and free-stream Mach number of 17.5. Similar calculations were scaled to the lower altitudes. Calculations for altitudes above 200,000 feet were in progress at the close of the period.

In the initial approach the plasma sheath was treated as consisting of a boundary layer and an inviscid outer region. The latter further was considered as comprising an inner entropy layer containing most of the high-temperature high-density flow (and therefore most of the ionized particles), and a weak shock layer to which small disturbance theory applied. The conditions investigated were those in which the gaseous elements that constituted the flow behind the shock were in equilibrium, nonequilibrium, and frozen states. This in-house theoretical effort was supplemented by a generalized viscous non-equilibrium study conducted by a contractor.

**THE SECOND PLASMA SHEATH SYMPOSIA:** In April 1962 AFCRL sponsored the Second Symposia on the Plasma Sheath and Its Effects, and brought together to Boston and Natick, Mass., more than 600 scientists and technical personnel. The symposia was a follow-up to one sponsored by the Laboratories in December 1959. The publication in 1960 of the proceedings of the latter, which were edited by AFCRL personnel, provided the scientific community with a definitive text on the entire subject up to that time.

In connection with the 1962 symposia, its principal findings included the following:

1. Antenna radiation patterns from re-entry vehicles showed large angular perturbations as well as attenuation, due to the effect of the plasma sheath. AFCRL plasma simulation experiments and theoretical studies have demonstrated that antenna directivity is so modified that communications will be severely impaired unless the effects are corrected. Since attenuation and voltage breakdown characteristics of antennas are quantitatively understood, remedial designs are possible.

2. The radiation characteristics of plasma-covered antennas were evaluated through the concept of leaky waves which enables a rapid quantitative estimate of the principal radiation parameters. This leaky wave concept shows that the radiation could be expected to be concentrated in narrow angular sectors for thick layers of lossless plasma.

3. Several scientific papers showed theoretically that strong magnetic fields applied to the plasma sheath may provide the answer and means for penetration. The radiation patterns for transmission and receipt also may differ drastically from each other because of the non-reciprocal behavior of anisotropic plasma.

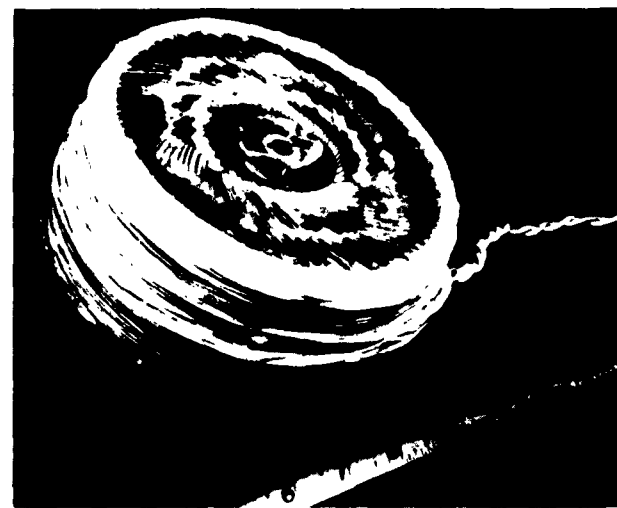
#### HYDROMAGNETICS RESEARCH

Another potentially fruitful area of plasma physics research—pursued by AFCRL's Optical Physics Laboratory—centered on hydromagnetics—the interaction of conducting matter with magnetic fields. New developments in the production of intense fields indicated that intensities as high as 2 million gauss and more were practical. Since such magnetic fields store as much as 400,000 calories of energy per cubic centimeter, there was a potential greater energy capacity than found in many chemical fuels. If methods of producing and containing such fields over an extended period of time could be developed, the possibility existed that practical propulsion devices might be designed.

**PRODUCTION OF SUPER-INTENSE MAGNETIC FIELDS:** During 1961-1962 research in magnetic field production led to the development by Optical Physics Laboratory scientists of methods for producing super-intense fields in the mega-gauss range, and methods for reducing forces through the use of force

free configurations. Measurements of the behavior of magnetic field producing coils at superconducting temperatures were carried out in cooperation with the Massachusetts Institute of Technology.

As a result of this work, a method of advantageously applying force-free configurations to superconductors was developed. It was found that the force-free coil possessed two specific advantages to superconducting magnets. First, because the currents and fields were everywhere parallel in a force-free coil, the current-carrying capability of superconductors was extended in that configuration; and secondly the deleterious forces attendant with large magnetic fields could be eliminated. The magnetic interaction of the plasma could serve as a method of converting the magnetic energy to a useful form. Also, the ionized gas—a non-tenuous form of an ideal conductor—provided the scientists an insight into the problem of producing



To obtain a force-free magnetic field, the wiring of the magnet must assume a precise and exceedingly complex configuration. The wiring for one such experimental force-free magnet is shown here.

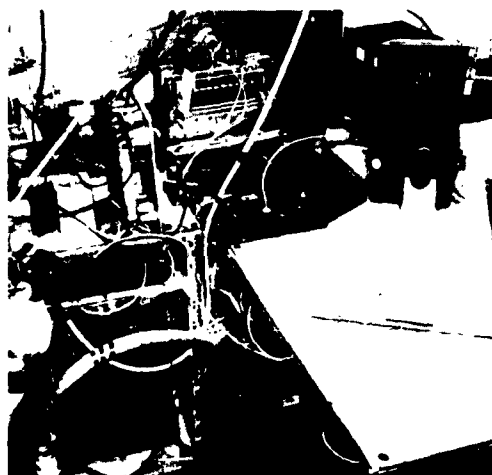
large fields without relying on mechanical strength. The AFCRL program gave particular attention to the existence, development and control of magneto-hydrodynamic instabilities which produce turbulence, jetting and other phenomenon.

During the period the problem was attacked on a number of fronts including: control of instabilities through the development of more and better stable geometries such as the force free geometry and cusp geometry; and the control of instabilities and jetting for utilization as mechanisms of heating and application to the problem of decoupling plasmas from magnetic fields.

#### **PLASMA CONTAINMENT AND STABILITY:**

In 1961 an AFCRL apparatus was constructed and tested as a method of controlling a plasma in a magnetic field. In this plasma containment device, called Romac (Rotated Magnetic Cusp), an attempt was made to combine the basic stability advantages of a four pole line cusp with the low loss rate of a mirror field. The magnetic field was produced by adding the components of the cusp field orthogonally to the mirror field. Then using pulse techniques, an ionized gas was created within a chamber and the Romac magnetic field produced transiently.

The variation in magnetic field combined with the basic instability of a plasma uniformly distributed through such a device led to a strong shock wave. Measurements made by Laboratory scientists, after the shock wave had passed through the center and been reflected to the outside of the device, indicated that the plasma had separated the mirror field from the cusp field so that only mirror field existed throughout the central region and mostly cusp field existed in the outer region. A subsequent increase of the applied cusp field led to a compression of the internal



In a magnetic cusp experiment, a plasma container is fed by four 12,000-joule condenser banks and an rf preionizer.

plasma and mirror field so that an intense dipole field was produced which was even larger than the maximum intensity of the applied mirror field.

The behavior of the magnetic field in the Romac experiment indicated several interesting properties of the configuration, which AFCRL scientists planned to exploit in future experiments. One was that the plasma created in the early stages of the experiment was undoubtedly unstable. The instability was such, however, as to create an inward flow of plasma rather than an outward flow as in most experiments. The development of the shock and its rise in intensity seemed to indicate that energy was being fed into the shock wave as it proceeded inward. This situation appeared entirely possible since plasma moving inward would gain kinetic energy as it moved from a region of high magnetic field to a region of lower magnetic field.

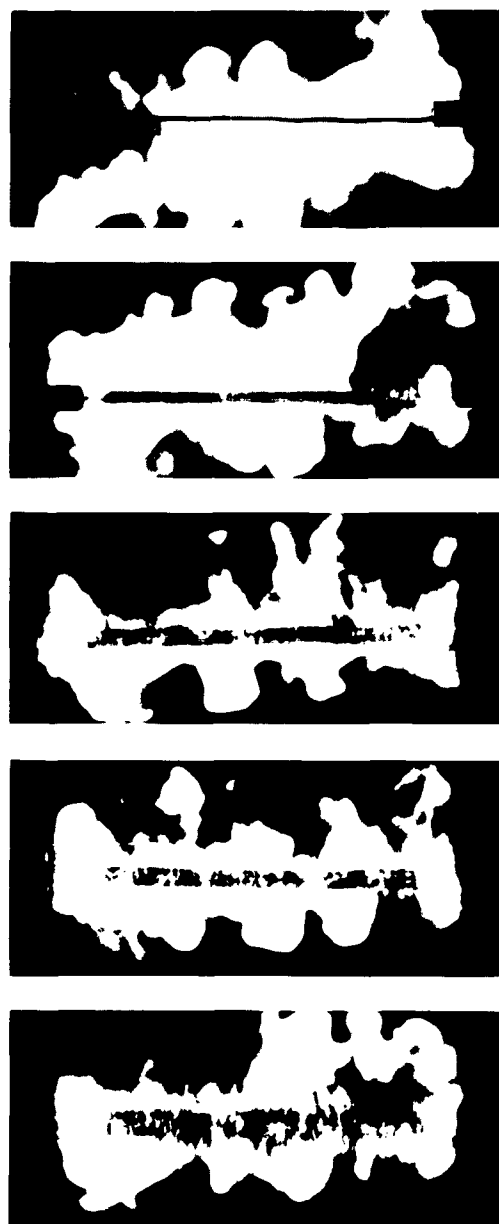
An unexpected result of the experiment was that during the initial phases of the second compression, the magnetic field in the central region was completely devoid of cusp components. This sug-

gested that there was plasma turbulence and it was believed that plasma turbulence accompanying the first shock wave was responsible for the separation of the orthogonal components of the magnetic field. The fact that the second peak was stronger than might be expected from the vacuum field was explainable in terms of a central cylinder of constant energy density being held in place by the cusp magnetic field which increases with the radius.

**EXPLODING WIRE STUDIES:** In some-related studies, the Optical Physics Laboratory utilized a historic technique for investigating plasma stabilities—the exploding wire phenomenon. This technique involves generating plasmas by discharging a large burst of capacitively-stored energy through a small wire. The combination of pressure and temperature caused when the wire passes from a solid to the vapor state in a millionth of a second, can then be used to study the behavior of both plasmas and materials under extreme conditions. For instance, the high energy density available in wire explosions gives scientists an opportunity to determine basic physical characteristics of materials in all three states of matter. It also allows study of energy transfer through conductors at density levels totally unobtainable by other means.

In addition, exploding wires have been used to produce shock waves, colloidal particles for propulsion, intense light pulses for ultra-high-speed photography, for electroforming of metals, and even for specific devices such as a blast shutter for capping rotating mirror cameras. This latter was developed by AFCRL scientists and not only outperforms previous capping shutters but, unlike earlier blast shutters, requires no high explosives.

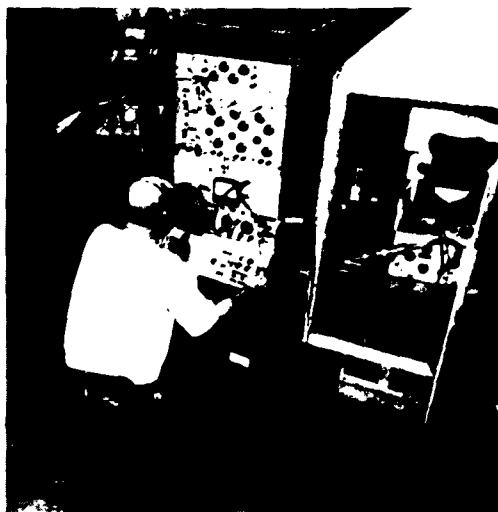
Although researchers have studied exploding wire phenomena since 1920,



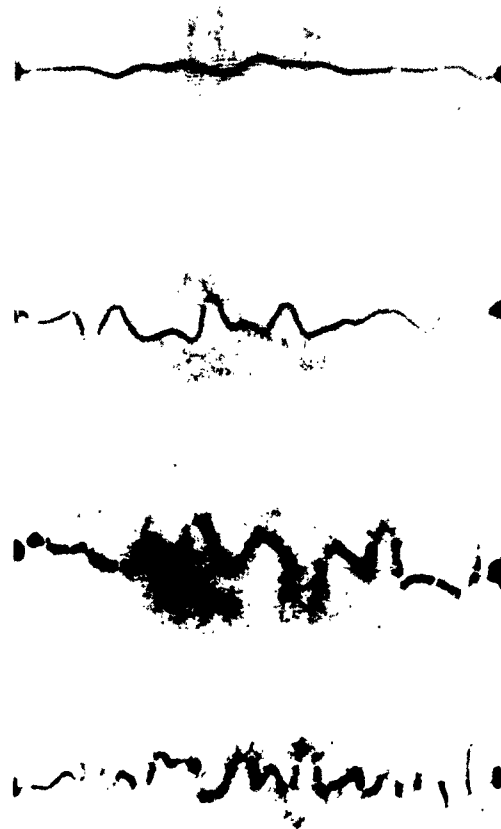
These photographs of a copper wire were exploded by approximately 200,000 amperes. Starting with the original wire and exposing at  $\frac{1}{2}$  microsecond intervals after the current starts to flow they show: original wire, melted wire, vaporization, and expansion. The exposure was about  $\frac{1}{4}$  microsecond and each picture was backlighted with another exploding wire placed 6 inches behind it.

the literature in this field remains very confusing since wires have been exploded under a variety of conditions of size, current and time. In order to clear up the confusion and to establish a better means of communicating with scientists in the field, a system of classification involving the phenomenological behavior of wires under different conditions was devised and published by AFCRL.

In connection with this work and the experimental program, in November 1961 the Second International Conference on Exploding Wires, attended by hundreds of scientists including investigators from Europe and Japan, was sponsored by AFCRL. It was evident from the 1961 proceedings that much duplication of research in this area had been eliminated, largely due to the publication in 1959 of the proceedings of the first exploding wire conference, also sponsored by AFCRL.



Wire is exploded behind the wooden barrier, next to the control panel. The flash of the exploding wire is monitored through observation port in wooden barrier.



The presence of dense material within the opaque cloud of a wire explosion was first demonstrated by AFCRL scientists using X-rays. It had previously been supposed that all material was in gas form by these late times. Photographs were taken at  $\frac{1}{2}$  microsecond intervals.

**SHOCK WAVE STUDIES:** In related research AFCRL scientists conducted investigations to uncover the effects of shock and turbulent motion in plasma behavior. To obtain the necessary data, an intensive theoretical study was carried out on shock waves propagated through fully ionized plasmas with and without a magnetic field. A study was made of the shock-broadening mechanisms in a plasma, and in particular of

the behavior with a finite electrical conductivity (which was found to have an oscillating fine structure).

These studies of magnetic shock waves in plasmas were extended to simultaneously account for the effects of viscosity and electrical conductivity. A two-fluid (proton-electron) shock structure model was developed which accounts for all of the classical transport coefficients simultaneously (viscosity, thermal conductivity, and electrical conductivity). This model had the advantage of fusing the newer two-fluid concept with the classical notion of the transport parameters in a fully ionized proton-electron gas. The magnetic shock structure model was reduced to a two-point boundary value problem of three simultaneous first-order, non-linear differential equations, which were then programmed for a computer. The solutions were expected to predict the structures of shock waves moving in plasmas across magnetic fields when viscosity and electrical conductivity were considered to be the only dissipative mechanisms. Later, the numerical computations were to be extended to also account for heat conduction.

Prior in-house investigations in this area dealt with the structure of shock waves in fully ionized plasmas containing no magnetic fields. The only dissipative mechanism considered was the diffusion of protons and electrons away from each other, owing to the great difference in their masses. The resulting charge separations created electric fields which themselves became additional pressure forces within the shock layers. Efforts were made to account simultaneously for both the diffusive charge separation just described and viscosity.

In addition to the above work, Optical Physics Laboratory scientists sought to arrive at a more complete description of a magneto-ionic theory plasma. Specifi-

cally, the effects of electron-photon and electron-electron collisions on the real refractive index and the absorptivity were evaluated for EM wave propagation to a fully ionized hydrogen plasma while under the influence of an external magnetic field.

#### **ELECTROMAGNETIC INTERACTIONS WITH PLASMA**

In their continuing search for new and improved aerospace detection and identification techniques, the scientists of the Detection Physics Laboratory also were interested in obtaining a deeper understanding of phenomena resulting from the interactions of fields and matter. During 1961-1962 a series of theoretical and experimental investigations were pursued by the Laboratory, in an effort to gain a greater insight into the nature of disturbed plasmas and their interactions with electromagnetic waves.

**PARTICLE DISTRIBUTION:** Of special concern to the scientists during the period was the determination of particle density distributions around orbiting satellites and other space vehicles operating at very high altitudes. Up to about 50 miles altitude the atmosphere was considered to be a fluid, and the continuum approaches of Navier-Stokes, etc., were applicable. At extremely high altitudes above 200 miles, free molecular flow exists. However, from about 50 to 200 miles there exists a transition region in which neither of these conditions is satisfied. During the period, Detection Physics Laboratory scientists studied the interactions of hyper-velocity objects through this transition region and into the free molecular flow regime using particle distribution function concepts.

Theoretical work considered the problem both from the point of view of the kinetic theory of neutral molecules and also charged particles, to attempt pre-



dictions of density variations for all regions of Knudsen numbers. When an absorbing body, such as a satellite, traverses a neutral plasma, the initial flow of electrons to the object exceeds the flow of positive ions and the body begins to acquire a net negative charge. As the charge builds up it repels more plasma electrons and attracts ions, so that the rate of charging flux tends toward zero. As a first step toward achieving a mathematical description of the amount of this build-up on complex body shapes, the scientists considered the simpler case of a flat plate. A direct solution was accomplished for the distribution function of a neutral plate travelling at satellite velocities in the free flow regime. From this solution, they were able to obtain the aerodynamic drag on this simplified "satellite" and to estimate the effective cross-section. The more realistic problem of a charged sphere was subsequently studied. This problem proved vastly more difficult but considerable progress was made through the use of orbit theory, similar to the approach used in neutron transport calculations. By the end of June 1962 the problem had been programmed for the 7090 computer and the scientists were awaiting the results of the calculations.

Supplementing the theoretical analysis, the scientists began the design of laboratory experiments to investigate the particle density distributions around simulated orbiting vehicles. To simulate the object travelling through space, controlled particle densities will be allowed to enter an evacuated chamber at the appropriate velocities and to impinge on selected body shapes inclosed in the chamber. In the initial experiments it was planned to utilize a flat plate as the "orbiting" body to validate previous theoretical calculations. Equipment was designed to provide vacuum capability

of  $10^{-10}$  mm Hg, electromagnetic beam focusing, a high temperature bath, and sensitive pressure transducers. An electron Schlieren camera for beam analysis was obtained to give direct measurement of both number density and velocity. At the close of the period, most of the equipment had been constructed and initial operation was expected in the near future.

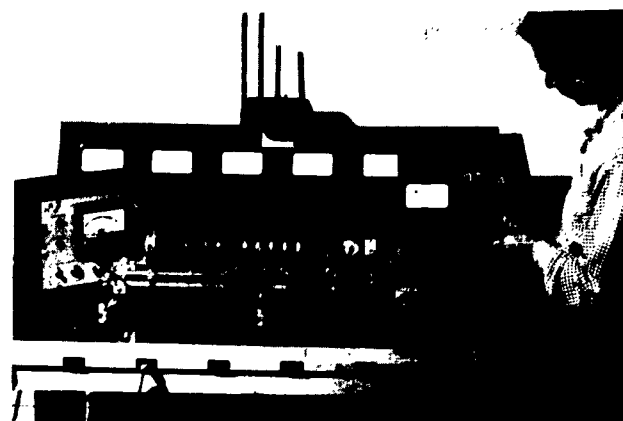
**GENERATION OF MAGNETOHYDRO-DYNAMIC WAVES:** Since many man-made activities in the ionosphere—the motion of large vehicles, explosions, exhaust gas expansions, etc.—would be expected to produce large scale movements of ionized gases, Detection Physics scientists predicted these events would act as a source of magnetohydrodynamic waves. In attempting a theoretical analysis of these disturbances, they found that while the gross dynamic structure could be described by the coupled equations of gas dynamics and electromagnetic theory, existing theoretical models for describing specific generating mechanisms and disturbance characteristics were quite inadequate. Little pertinent experimental data was available since the number of controlled experiments undertaken had been exceedingly few and very narrow in scope. Numerous calculations made using various assumptions led to the conclusion that MHD waves must be present in the ionosphere as a result of many of these activities. However, neither the magnitude nor the extent of these effects could be firmly established. Another unresolved question related to the amount of energy actually transferred from the particular man-made event, and whether or not this amount was sufficient to be significant. During the period the Laboratory continued efforts to resolve such questions, as well as tackling the formidable problems of variable conductivity, attenuation effects of neutral particles, and

energy distribution in the various modes in order to provide more effective theoretical formatisms.

Supplementing these analytical approaches, the Detection Physics Laboratory also initiated a program of controlled experiments to obtain direct measurements of some of the parameters. Equipment was constructed to produce a sustained quiescent ionized medium in a static magnetic field. By perturbing the magnetic field, wave-like disturbances were induced in the medium, and were measured as they propagated in the plasma. Although numerous equipment difficulties were encountered in the initial work, sufficient preliminary measurements were obtained to validate the experimental design and equipment modifications were initiated.

In the above experimental setup, a hydromagnetic wave guide consisting of an ultraviolet tube 2.5 cm in diameter and 78 cm in length, mounted concentrically within another tube 7.5 cm in diameter, is used to produce a continuous cesium plasma. Cesium was chosen because of its low ionization potential and relatively high vapor pressure. The tube temperature is closely controlled to produce uniform diffusions to the walls. A variable coaxial magnetic field, uniform to one tenth of one percent at 500 gauss, coupled with pressure ranges of 1/100 to 50 microns, provides the necessary flexibility to verify the Alven phase velocity relation. The system was designed so that a rapidly collapsing magnetic field, produced by a pulse discharge, gives rise to a radial wave which can be monitored by double probes and magnetic sensing loops to determine the group velocity.

The scientists made extensive theoretical calculations to determine the mode structures in the hydromagnetic wave guide. The results indicated that the



A classical Langmuir probe is used to determine energy distribution and temperature of charged particles within a striated plasma. The electrodes of the simple diode discharge tube are movable allowing the entire effective length of plasma to be probed.

phase velocity is mode dependent, and that proper frequencies exist to allow propagation with little attenuation. By mid-summer 1962 most of the modifications had been completed and additional experiments were expected to begin after the equipment had undergone final testing.

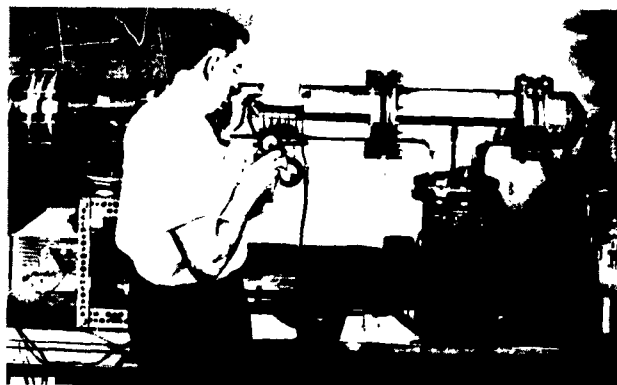
**CROSS-MODULATION OF ELECTROMAGNETIC WAVES:** In related research, Detection Physics Laboratory scientists investigated the interaction of hydromagnetic waves with high frequency electromagnetic waves. A review of the classical Bailey-Martin theory of cross-modulation was undertaken to develop analogous theoretical expressions for hydromagnetic - electromagnetic cross-modulations. From these studies it was concluded that MHD waves with very low frequencies are well suited for cross-modulation effects. The scientists developed a theory for electromagnetic waves in a plasma leading to a dispersion relation that depends explicitly on the velocity distribution function of the

electrons. The complex index of refraction was determined by the isotropic part, and an expression for the time independent part of the relation was derived. The time dependent part was reduced to a problem of solving a pair of simultaneous second order differential equations.

In addition to these theoretical considerations, the Laboratory at the close of the period was planning a series of controlled experiments to investigate the cross-modulation phenomena. When the hydromagnetic wave tube (described above) becomes operational, the scientists plan to transmit radio signals through the hydromagnetic waves to directly measure such effects as the magnitude of transferred modulation, frequency dependence, and the effects of relative geometry.

#### **PHYSICAL PROCESSES OF COSMIC GAS AND PLASMA**

A magnetohydrodynamic study of interplanetary gases also was pursued



An X-band microwave interferometer, whose free-space radiating and receiving elements are completely enclosed by an evacuated chamber, is pictured. A plasma is created within the vessel by induction techniques at 10 Mcps. Plane waves of electromagnetic energy are launched by a surface wave antenna structure and interact with the ionized medium.

during the reporting period by the Ionospheric Physics Laboratory. This in-house theoretical study dealt with interplanetary matter given off by the sun and affected by its rotation and dipole magnetic field. A supporting contractual effort in this area included work by Italian and German researchers on nebular variable stars, and galactic nebular investigations. The immediate purpose was to obtain new knowledge of the internal structure and density in gaseous nebulae such as the Orion nebula, and the nature of stars that seem to be in the process of formation out of the nebular gas and dust. These nebulae contain spheres of hydrogen plasma expanding supersonically into regions of neutral hydrogen gas.

AFCRL also sponsored (jointly with NASA) the construction of a 24-inch aperture satellite telescope to uncover new knowledge of the atoms and molecules of the interstellar gas of the galaxy, currently impossible to detect from the earth or from balloons or rockets. In addition to the above, joint funding with the National Science Foundation will provide a 60-inch telescope in Chile that will permit in-house research as well as extending to the region of the galactic center a pioneer study (under contract) of the magnetic fields of the galaxy. During the period another AFCRL contractor nearly completed a definitive solution to the kinematics of galactic rotation. A radial expansion was found to be in agreement with radio astronomy results for neutral hydrogen atomic gas.

In Australia partial support was given to a unique 600-foot optical intensity interferometer program to determine the angular diameters and temperatures of over 200 bright, hot southern stars. Several equipment development programs were supported. One of the latter included the fabrica-

tion of a luminous shock tube to act as an optical source at the temperatures of stellar atmospheres but under precisely measured conditions of temperature, pressure and density. This device, combined with a time-resolved spectrograph Mach-Zehnder interferometer now available and other specialized equipment under construction, made possible an in-house research program that was being accelerated at the close of the period. The principal objective of this program is the determination of the absolute transition probabilities ( $f$ -values) of astrophysically interesting spectral lines.

The Ionospheric Physics Laboratory in-house program of spectroscopic studies during 1961-1962 also encompassed: (a) high resolution spectroscopy of astrophysical sources using a Czerny-Turner spectrometer and a Fabry-Perot interferometer at the focus of a large telescope; and (b) interferometry of 5200 Angstrom line in the aurora and the nightglow in order to determine the wave-lengths of the two members of the doublet with an accuracy of plus or minus 0.01 Å. The first studies were conducted on the Doppler profiles of the forbidden atomic oxygen lines in aurorae and airglow.

#### **ELECTRICAL PROPERTIES OF PLASMA**

The physical electronic aspects of plasma physics also was of interest to the Electronic Material Sciences Laboratory, which during 1961-1962 was engaged in research into the basic properties of gases as electronic materials which might be used for amplification, frequency and energy conversion, electromagnetic wave generation, etc., and into the potentialities of high temperature plasmas.

**ULTRA HIGH TEMPERATURE PLASMA RESEARCH:** This in-house research was aimed at obtaining a better understand-

ing of the physics of extremely high temperature plasmas at atmospheric pressures and above, as well as in the low submillimeter ranges. At high pressures where thermalization is a limited problem, AFCRL scientists found that intensely brilliant light pulses could be produced in high current ( $10^7$  amps/cm<sup>2</sup>) electrical discharges of nanosecond duration. These pulses had a number of potential uses in several fields of research and technology, including study of high velocity turbulence in fluids by means of ultra high speed photography and the study of carrier life times in photo detectors; and in the study of chemical reactions by photo flash photolysis and applications of pulse lasers.

The program of ultra high temperature plasma research encompassed four interrelated sub-areas; (a) high pressure, ultra high temperature plasmas; (b) low pressure, ultra high temperature plasmas; (c) nanosecond discharges including electro-optical research in the  $10^{-10}$  sec realm; and (d) application of



By capacitor discharge techniques AFCRL has been able to generate extremely brilliant light sources of short duration. This light source has been used for photographic instrumentation of Air Force wind tunnels.

nanosecond light pulses for studying instantaneous or high speed processes.

In the first area the AFCRL effort was directed at establishing the upper temperature limits in high pressure discharges, where thermal conditions could be shown to exist. While it was believed that radiation loss determined the upper limits, there was evidence that the plasma became unstable. Indications of pinch and instability appeared during in-house studies of nanosecond discharges. In this continuing research, new measuring techniques or modifications of old ones were applied during the period to a comprehensive study of thermal conditions in discharges where the current density exceeds  $10^6$  amps/cm<sup>2</sup> in discharge times from  $10^{-6}$  to  $10^{-9}$  seconds.

In the second category at low pressures, thermalization—if it exists—was believed caused by acceleration, compression and confinement and final coalescence of plasma structures being internally produced and ejected into a cusp shape geometry by intensely strong magnetic fields. However, existing measuring techniques in this area were marginal for observation of the interaction and thermalization processes. The in-house approach to resolve the problem involved use of magnetic probes, gated image converters with minimum time jitters, applied in connection with photomultipliers covering wide spectral ranges of observation including the vacuum ultraviolet and X-ray regions.

One of the highlights of this ultra high temperature plasma research was the development of nanosecond light sources having sufficient brilliance for single shot photography of very high speed phenomena. These sources were used to advantage in the study of fluid turbulence, and several of the devices were sent to other organizations for use as

tools in experimental physics. At the end of June 1962 a study was published on the carrier life times in photo conductors when illuminated by nanosecond light sources.

**GASEOUS ELECTRONICS:** Besides their research in the solid state,\* personnel of the Electronic Material Sciences Laboratory sought during the period to obtain new knowledge of the ionized gaseous state of matter as an electronic material which might have electronic applications.

This effort fell into three distinct phases: (a) the production of a suitable plasma involving the breakdown of ultra-pure gases in appropriate containers (somewhat analogous to the ultrapurification and crystal growing phases of the solid state research program); (b) the determination of intrinsic properties of the plasma—repeating, extending, and improving standard diagnostic techniques, and generating novel approaches to plasma properties; and (c) application of the plasma state to electronic usage.

In order to obtain meaningful plasma data, the gases employed were maintained at carefully controlled purity levels (in certain cases, impurities below one part in one hundred million were required). Mass and optical spectrographic, as well as ion cyclotron techniques were employed to determine the amount and character of residual gases in systems. Sophisticated purification techniques such as selective pumping by gettering and cataphoresis, use of molecular sieves, filters, and cryogenic techniques also were required and utilized.

Three efforts highlighted the Laboratory's work during the period:

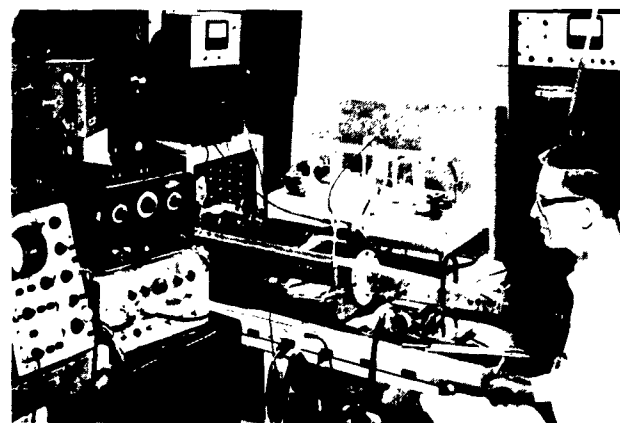
1. A guided propagation experiment using 10 centimeter microwave probing radiation. By conducting this experiment at 10 centimeters, rather than the

\* See Chapter III.

generally employed three centimeters, several important advantages were realized. These included lessening of wall effects as a result of greater container diameter, and increase of measurement span due to a longer plasma-microwave interaction path. With this improved apparatus, the scientists were able to make basic high-precision measurements of density, collision frequency and recombination coefficients. Initial measurements were made on nitrogen gas because of its importance in ionospheric processes. Future measurements will employ rare gases, namely helium and neon. Initial results with nitrogen provided an insight into the mechanisms which produce anomalously high electron temperatures in the late afterglow of experimental plasmas.

2. A free-space or interferometry experiment at three centimeters. A novel diagnostic method was developed which brings several useful innovations to the standard interferometry technique. The use of traveling wave antennas completely contained within the vacuum envelope permits measurement of a plasma which requires no dielectric walls (over certain pressure ranges) to confine the plasma. In this manner, troublesome container walls and their resulting interface problems can be eliminated. As an added advantage, the thickness of the plasma sample under investigation may be varied at will. To date, CV measurements on rare gases ionized by induction at 30 Mc indicate electron densities ranging from  $4 \times 10^{10}$  to  $8 \times 10^{11}$  electrons/cc. and electron collision frequencies of  $5 \times 10^6$  to  $7 \times 10^{10}$  collisions/sec.

3. In addition to the above, a plasma post experiment was designed to determine electron collision frequency and number density by measurement of light output in a decaying plasma. Theoretical considerations indicated that the



A ten centimeter microwave dielectrometer is used to determine dielectric constants and loss tangents. The plasma post to be measured is inserted into a waveguide section (left center). VSWR and change in position of minimum are determined by the operator. From this data, the density and collision frequency of the ionized medium may be deduced.

light output in a decaying plasma may be correlated to the electron collision frequency and density. To validate the theoretical interpretation, a microwave post technique will be employed in future experiments.

The above efforts not only yielded useful plasma data but also resulted in development of several novel AFCRL electronic devices, noteworthy among them being a plasma microwave energy detector, and a plasma waveguide tuner.

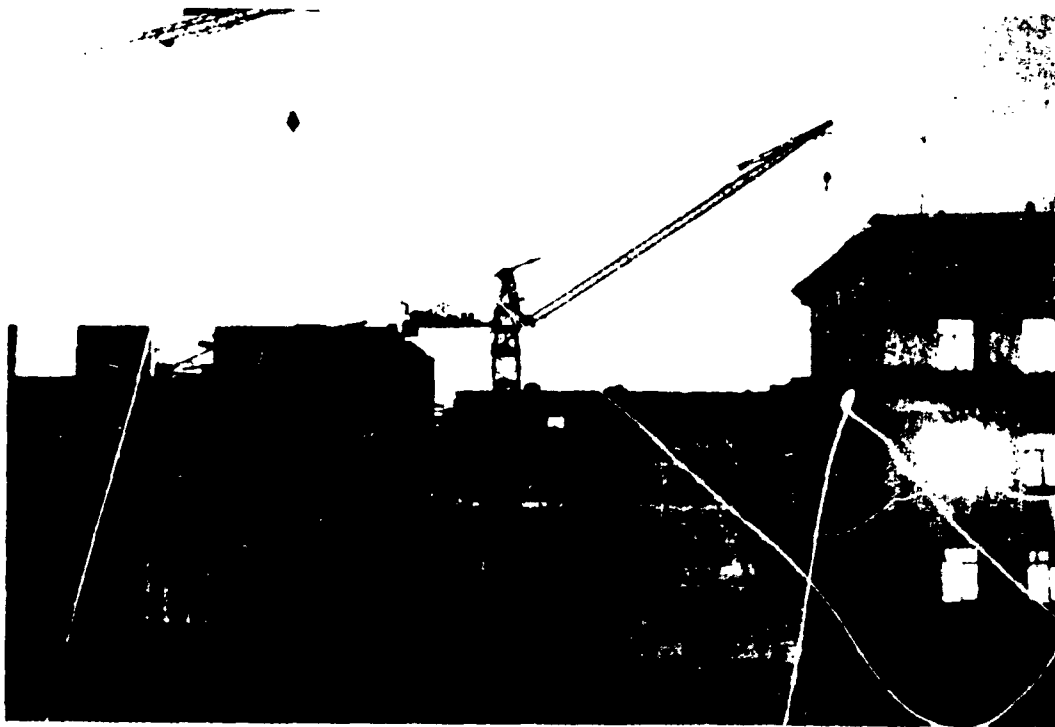
**HIGH VACUUM RESEARCH:** Since many plasma, gaseous and solid state applications depend on precise knowledge of high vacuum conditions, the Electronic Material Sciences Laboratory's high vacuum research efforts during 1961-1962 was an important supporting project. The objective of this work was a better understanding of high vacuum pumping and gauging techniques, and of the importance of residue

and entrapped gases in experiments which aimed at simulating outer space, or which dealt with evacuated electronic devices or surface effects.

The in-house research was directed toward three goals: (a) continuing improvement of ultra-high vacuum technology, including new sealing techniques and new materials adaptable to precise experiments in vacuum and plasma electronics; (b) studies and comparisons of various partial pressure measuring techniques, particularly research on and comparison of omegatron and sector-type mass spectrometers for various gases for various pressures; and (c)

continued study of trapping, attachment and release of gases by surfaces of solid materials. In addition, consultation and design assistance on high vacuum technology was furnished to several of the laboratories.

Supporting contractual work during the period included: (a) an investigation of gases evolved from electron tube parts under varying conditions of pressure, temperature and time; (b) a study of semiconductors as emitters of electrons for high vacuum devices; and (c) studies of the laws governing surface and bulk absorption of gases in the very low pressure ranges.



The kugelblitz, or ball lightning, is a little understood phenomena. As shown in this photograph taken from a Russian journal, the path taken by these small plasma balls often is highly erratic. During the reporting period, AFCRL attempted to create artificial ball lightning in the laboratory.



Two AFCRL groups are directly concerned with research in the information sciences: The Computer and Mathematical Sciences Laboratory and the Communication Sciences Laboratory. Information sciences comprise that body of scientific knowledge, methodology and techniques necessary for the acquisition, transmission, transformation, evaluation, ordering, filtering and interpretation of information. As used in this chapter, information is defined as "encoded knowledge."

The goals of this Air Force research are obvious, but need to be restated since the paths for reaching them appear to lead in divergent directions. AFCRL goals in the information sciences as they relate to data processing are to conceive and explore technologies leading to new machines with increased reliability, higher speeds and greater "intelligence." The goals of the in-house research as they relate to communications are to transmit "more" information over greater distances, with increasing reliability and security. While all of these qualities may be desirable in a single system, it sometimes becomes necessary (depending on the particular application) to trade off many desired characteristics to assure one is achieved.

During 1961-1962 three areas of AFCRL research in the information sciences emerged and grew in importance. They included: studies in biophysical systems, in speech processing, and research into new computer languages—that is, improved techniques for instructing computers. Intimately associated with these efforts was a program of in-house work in network



theory, mathematical analysis and pattern recognition techniques.

In connection with this work, there is a strongly-felt need in the data processing and communications fields for microminiaturized components. Although the miniaturization of components is an activity embracing all of electronics, the two AFCRL Laboratories working in the information sciences provide most of the command's support for a predominantly contractor research effort in integrated circuitry and molecular electronics. Aside from this contractor work, most of the information sciences research reported in this chapter is largely accomplished in-house.

In the communications research area, at the close of the reporting period AFCRL was operating a number of new facilities for the processing and evaluation of speech signals. These facilities provided the organization some of the most advanced equipments in the world for the analysis of human speech. They facilitate the manipulation of complex waveforms that give a unique character to individual words when spoken by different speakers under a range of emotional contexts. The data processors in this program are considered to be mere tools, since the research is not primarily aimed at improving equipments as such. However, the design and construction of specialized computers is required for research of this type.

**AFCRL COMPUTING ELEMENTS:** In the course of their research into improved information processing and communication techniques, AFCRL scientists have had access to a variety of data processing facilities. These equipments are used for the overall computational needs of the Laboratories, for experiments involving improved computer design and techniques and, as indicated in the case of the in-house speech research program, as highly specialized data processors.

During the period one general purpose in-house digital computer (IBM 650) was available to AFCRL scientists as a service facility. The IBM 650 was used for a total of 1777 hours on scientific problems originating in 15 different research projects throughout the Laboratories. These projects covered such tasks as: determining the average wind speed and direction from the height, elevation and azimuth angles for each minute of ascent of rawinsonde soundings; numerical analysis to determine the electron density of the ionosphere from rocket data; and determining the impedance and standing wave pattern of a helium plasma.

Because needs greatly exceeded the capacity of this machine, the Laboratories found it necessary to contract for computer services, programming and data preparation. A total of 647 hours of computer time at a cost of \$231,000 was contracted for during fiscal year 1962. Thirty-three different research projects were supported in this manner. In addition, AFCRL programmed a limited amount of computer time on a Philco 2000 located at Hanscom Field and operated by the Electronic Systems Division. The Laboratories used 490 hours at a cost of \$52,000. For programming and data preparation services, \$159,000 was expended during the fiscal year.

At the close of the period AFCRL also installed a new machine, the Research Data Evaluator (RDE), a fairly large installation but with limited input-output capacity. By January 1963 AFCRL plans to replace the 650 computer with a modern, medium scale general purpose computer of much greater capacity. While both the RDE and the new general purpose computer will alleviate the serious data processing problem that existed throughout 1961-1962, still another large-scale digital computer

installation will be required to handle the huge computational burden generated by AFCRL scientists. Until such an installation is approved, considerable contract machine time will be bought.

In addition to these general computational machines, the scientists have utilized five specialized data processors. These are: the Cambridge Computer, the Voice Data Processor, the LINC Computer, the Experimental Data Processor (DX-1), and the Analog Ray Tracer Computer. The first three equipments are discussed elsewhere in this chapter; the latter two are described below.

The Experimental Data Processor was delivered to AFCRL in the spring of 1962. This machine is of a class of specialized digital computers that are being used on an increased basis in research laboratories. Processors of this type are designed for statistical processing of large volumes of data—waveforms, patterns, components of speech, etc. The input consists of statistical prediction, estimation and classification. The processor is distinguished by the fact that the operator, by novel displays, can monitor the data reduction process and intervene and control the course of the analysis while the experiment is in progress. In a sense the program can be constructed or refined during analysis. Work performed on the processor has included such problems as ballistic missile detection, and studies involving on-line adaptive filter design techniques.

The Analog Ray Tracer Computer was placed in operation in March 1961. This is one of the largest analog computers in the world. It actually consists of two Pace (Electronic Associates) 231-R analog computers with two variplotters and two 8 channel recorders for display. Problems involving ionospheric trapping of electromagnetic waves, correlation of signals to and from the moon, behavior

of non-conducting ferromagnetic materials in magnetic fields, controlled carrier loop studies and analysis of a set of partial differential equations representing the diffusion-kinetics of night trail generation, were solved on this equipment during 1961. A total of \$108,000 to support the analog computer programming and operation was expended during fiscal year 1962.

#### BIOPHYSICS

The neural systems of mammals hold great fascination for network theorists and mathematicians. This fascination stems from the simple fact that they already know that construction of a system with the brain's tremendous capacity, reliability, memory and efficiency is possible in principle.

There are two basic approaches to deciphering the mechanism of biological systems, one inductive, the other deductive. In the first case, the scientist examines the neural system of mammals, subjects these systems to various tests, and from these experiments attempts to diagram features of the operating system. In the second, the scientist does



The Experimental Data Processor (DX-1) permits the processing of sensory data on a real-time basis. Data are displayed on the large color console shown in the center of the photo.



The human brain contains some 10 billion neurons of the type shown here under extreme magnification. Scientists have barely approached the threshold to the understanding of the complex mechanism of the brain.

not set out to duplicate the structure of neural systems, but attempts to apply all that is known of physics, chemistry and mathematics to approximate some aspects of their performance. Through this process the researcher may come up with networks that may have little similarity to those found in neural systems, but if they are efficient networks it is considered unimportant that they are not facsimiles of neural systems. At AFCRL both approaches are being taken in biophysics research.

**BIOLOGICAL STUDIES:** The Laboratories first undertook work in biophysics in 1959 in cooperation with neurophysiologists at the Massachusetts General Hospital. This initial study was completed early in 1962. The work grew out of an AFCRL attempt to prove that the nerve fibers connecting the eye to the

visual cortex were not randomly organized, as was frequently assumed.

The work was begun at a time when many computer people thought it possible to build completely "random" computers—that is, machines with elements connected together in a random fashion. It was thought that these computers might be able to learn to organize their connections through experience. Behind this concept was the apparent example found in nature—the lack of discernible organization in the fibers leading from the eye to the brain.

On the basis of purely mathematical considerations, one of AFCRL's scientists has shown that a completely random machine capable of organizing itself was not possible. These mathematical considerations likewise indicated that connections between the eye and higher cortical centers in mammals could not be assumed to be random. It was then necessary to find in mammals some constraints on randomness. In the AFCRL study conducted in concert with the neurophysiologists at Massachusetts General Hospital, it was found that constraints do indeed exist. A report on this work was published by AFCRL in July 1961, entitled: "Some Metric Considerations in Pattern Recognition." An important result of this study, noted in the above report, was that those neurons in the visual cortex governing vision must necessarily be aligned two-dimensionally—that is, on a plane.

**AFCRL NEURAL LABORATORY:** As a result of this initial effort in the biosciences, AFCRL acquired a valuable background in neurophysiology to complement existing experience in computer technology. This biological research led to plans to establish a larger and more formal in-house neural study program. At the close of the period laboratory

facilities for this program were partially completed. A special computer, the key instrumentation for the new research, was designed and was under construction. This equipment, known as the LINC computer, permits the direct real-time processing of electrical signals from the brains of mammals. It is similar to a Lincoln Laboratory prototype, with certain modifications introduced by AFCRL.

When fully operational in the latter part of 1962, the neural research group will concentrate on the analysis of the waveforms of animals—primarily rats. Although waveforms have been observed in mammals for almost 100 years, no meaningful interpretation of these waveforms has emerged because of the time required to manually reduce the data. The LINC computer will permit AFCRL scientists to monitor the experiments while they are in progress, and to make various tests as these appear appropriate to the researchers during the analysis.

The LINC computer can handle eight channels of information, or information from eight electrodes simultaneously. The signals from the electrodes are converted from analog to digital form. In the past most of the work done on waveforms has considered gross areas of the brain. The AFCRL approach will attempt to correlate patterns obtained from gross areas with patterns from microelectrodes capable of measuring the output from a single neuron, or from a small population of neurons. One of the first experiments to be conducted in-house will be a study of the visual cortex as it is affected by stimuli of various intensities and repetition rates. Particular attention will be given to the expansion of waveforms outward from various centers, which may furnish clues to the brain's awesome capacity to retrieve and recall information.

In connection with the scientists' plan to use the LINC computer to make direct measurements of signal propagation through the brain, theoretical work on such propagation had been previously accomplished by AFCRL, on the basis of extrapolations from known physical, mathematical and chemical processes. From this work an interesting conceptual model of the process by which the brain recognizes and orders objects in a visual field was developed. This model is of interest to researchers engaged in pattern recognition studies at AFCRL.

Another effort falling within this general framework of neural model construction concerns studies of redundant networks. The objective was to determine for any desired level of reliability (i.e., redundancy) the minimum number of extra elements needed. As a result of the latter research, the scientists were able to make a number of distinct contributions to the mathematics of redundant circuits.

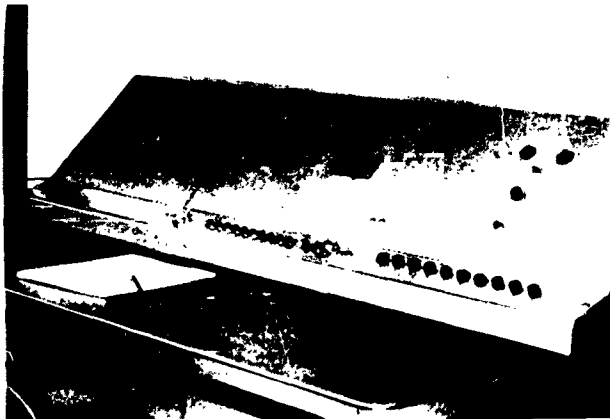
**EXTRA SENSORY PERCEPTION INVESTIGATION:** A study of psi phenomena by AFCRL scientists also was undertaken during the period. Begun in the spring of 1961 this study was completed, except for statistical analysis of results, by the end of June 1962.

The field of psi phenomena is troubling to the scientist. To admit the possible reality of the phenomena would seem to admit to the existence of a force in nature that must share a role with gravitational, electromagnetic and nuclear forces. Nevertheless, certain apparent manifestations of the phenomena seemed to warrant scientific study. In this connection, it was noted that Soviet scientists, judging from the technical literature, were stepping up their investigations in the field.

AFCRL approached the matter with a certain caution. The first step in the effort was to design and build a random

number generator that would permit the completely automatic scoring of results and thus avoid any unconscious bias that might exist on the part of the scorer. This machine is one of the best of its kind ever constructed. It permitted two tests: (a) the subject could attempt to predict the number to be generated, and (b) he could guess the number that had already been generated and displayed on the machine located in a separate room.

To conduct these tests a large number of subjects were needed. For this purpose AFCRL solicited the support of



The random number generator used in AFCRL's tests of extra sensory perception is shown here. Subject below attempts to predict the next number to appear on the number indicator.

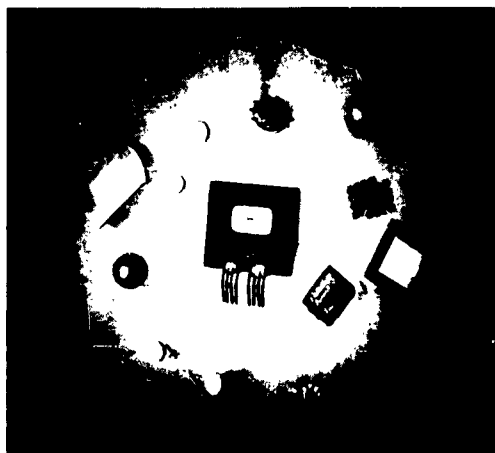


Endicott Junior College, Beverly, Mass. Tests were made by Endicott (without cost to the Air Force) on 45 carefully selected subjects. One hundred controlled tests were made with each subject in each of the two test modes. At the end of June 1962, the results were being statistically processed. These statistics may or may not indicate a significant deviation from statistical norms. However, based on preliminary analysis, the distribution seems to be quite random.

In considering the replication of mental functions, an obvious limitation centers on the number of elements in the human brain, some 10 billion, as compared to the 200 thousand or so elements found in the largest general purpose computers. Although solid state physicists are still far from achieving the remarkably efficient packaging of the human brain, progress already made in the microminiaturization of components represents one of the single most revolutionary technological developments of the past several years.

The Cambridge Research Laboratories, through contracts with a large number of companies — Texas Instruments, Philco, RCA, Motorola—has contributed to the rapidity of this advance. The AFCRL-supported work is carried out under a variety of designations: molecular electronics, integrated circuitry, thin film technology, etc. These techniques involve diffusion, etching, masking. The result is that new elements performing the work of conventional circuits have been reduced to microscopic sizes.

The fabrication of hundreds or thousands of active devices in areas of only a few square inches is now within reach. These can be constructed fairly simply and economically, and this fact has given rise to a number of new computer concepts. These are known by such names



Through contracts with a number of companies, AFCRL is advancing the state-of-the-art in the design and fabrication of microcircuits.

as spatial computers, iterative logic nets and nets of formal neurons. They have in common the fact that structurally they represent vast networks of large numbers of rather simple logic blocks. Functionally, they are capable of an extremely high degree of parallel operation, great flexibility and potentially great resistance to failure. The latter quality grows out of their simplicity and the fact that their economy and small size permits a great deal of redundancy.

The rapid advance in miniaturization and mass production of computer elements has provided the mathematician and the computer technologist new and exciting design materials. Entirely different logic structures are possible. The full potential of these new building blocks has only recently been realized. They have yet to be exploited.

**LOGIC NETWORK STUDIES:** The low cost per element and the small size of the elements permits the network theorist great extravagance in their use. There is open to him an infinite number of interconnections to be considered. He is no longer confined to the sequential

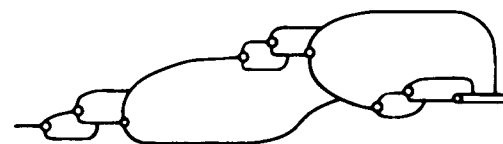
operation and the serial flow of information of the conventional data processor.

The network theorist is permitted to design for the parallel processing of information. A second important aspect is the external control of interconnections between elements. The latter permits the theorist, in effect, to "rewire" the computer for each specialized computational job. He also has certain constraints when designing networks using the new elements. He must fabricate reliable nets from basically unreliable elements. It is neither possible nor desirable to fabricate individual elements with great precision.

One recent design is the homogenous net, which has given AFCRL some interesting results. A homogenous net consists of a net with  $m$ -inputs and  $n$ -outputs, each element of which also has  $m$ -inputs and  $n$ -outputs. Such a net is illustrated on this page.

Organized complexity can be introduced into this net by replacement of each element by a copy of the net itself. If this replacement is made  $n$  times, the net is said to be iterated. If each element is capable of performing a given set of functions, each with prescribed probability, several important questions then suggest themselves. For example:

1. What is the set of output functions of the net after any given number of iterations?



Arbitrarily high reliability can be achieved by the use of redundancy. One method for doing this is the replacement of each element in the net by a copy of the net itself. The above net can be continued to any order of redundancy and thus reliability.



NO. OF ITERATIONS	PROBABILITY OF "AND"	PROBABILITY OF "OR"
0	.75	.25
1	.8438	.1563
2	.9344	.0656
3	.9877	.0123
4	.9996	.0004

The above net can be iterated—repeated—indeinitely. If a single element gives the desired "and" output 75 percent of the time, successive iterations will result in the increased overall net reliability shown in the table.

2. Does this set of functions become stable—that is, does there exist a place in the iteration sequence as such that all subsequent sets of output functions are the same? (If so, the net is said to converge.)

3. If the net converges, and the element functions are known only with prescribed probability, what is the probability that the net will realize a particular output function?

4. Is it possible for a particular function to be realized with an arbitrarily high degree of predictability by iterating a net a sufficient number of times?

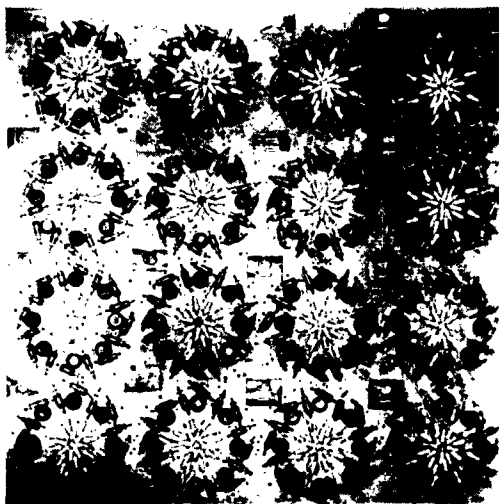
The improved reliability through four iterations is shown on the table on this page. Also shown is a schematic of the net which will give this improved reliability. If each element performs either an "and" or an "or" operation with probabilities  $p$  and  $q$  respectively, it can be shown that for  $p > \frac{1}{2}$  successive iteration will yield arbitrarily high reliability. The table illustrates this situation for  $p = \frac{3}{4}$ ,  $q = \frac{1}{4}$ . Several papers and in-house technical reports have been prepared on this subject.

**EXPERIMENTAL MICROMINIATURIZED COMPUTER ELEMENTS:** When an attempt to fabricate the iterative micro-miniaturized networks described above

is made, it is found that although the high density packaging of micro-miniaturized elements is indeed feasible, practical considerations stand in the way of the essential analysis that must be made of these nets prior to fabrication. The microscopic size of these elements makes it difficult to fabricate experimental circuitry for tests.

A solution to this dilemma is to fabricate test elements from conventional transistors, resistors and capacitors in such a way as to simulate the operation of integrated circuitry. To accomplish this AFCRL has developed flexible logic elements that have general utility in considering logic networks using integrated circuit techniques. These elements operate with digital information signals and digital control signals. One in-house array is pictured on this page. Each element is connected to its neighboring elements with fixed physical connection but with provision for external control of the electrical interconnections. This latter consideration which provides a flexible means for rearranging interconnections once the unit is constructed is believed to be an essential feature in future data processing devices.

The logic function performed by the



Conventional elements—transistors, resistors and capacitors—are used in circuits designed to simulate the operation of microcircuits. Microcircuits are simulated because they are too small for adequate experimental analysis.

element is "nor" and an array of these elements can realize many different data processing structures by external control of the electrical interconnections. The schematic array of such elements is also illustrated on this page. Each element has eight neighbors and the information or signal connection between are indicated by arrows. In AFCRL's simulated network, interconnections are controlled by means of solar cells. Light can be used to change the elements from an active part of the net to simple conductors, in which case they are simply by-passed.

In a microminiaturized circuit, solar cells may not be a suitable solution. More sophisticated techniques of control are under investigation.

**PATTERN CLASSIFICATION:** Networks of the kind just described promise to play a major role in pattern classification. Pattern classifiers are important in that they permit the data processor

to work directly from sensory data. Effective machine techniques for reading printed material and performing logical operations on such sensory inputs have until now largely eluded researchers. Many techniques have been evolved, but they are crude, slow and often respond only to carefully selected characters. AFCRL scientists during the reporting period investigated several character reading techniques and associated logical networks. One of these is described below.

Pattern classification is a finely developed attribute of human intelligence. In designing methods for duplicating man's capability to catalog numbers and letters, a popular approach is based on an analysis of the loops, angles, open ends and so on of a given character. AFCRL has designed a classifier that operates on an altogether different principle, and is currently implementing the construction of the device through a contract with Philco Research Laboratories.

The AFCRL device involves several operations performed on each letter being classified into one of two major classes. Next the classifier analyzes it for its sub-class. In this manner, through successive sub-classes, the classifier narrows down the range of possible classifications until the letter is identified.

The classifier consists of an array, or grid, of identical cells. Each of the cells can exist in one of two states; zero, the original state, or one. The cells are connected in such a way that a change in the state of all the cells can be propagated across the array from the right, the left, downward, or upward. By projecting a two-dimensional pattern on the array, thus illuminating certain cells, the state of the illuminated cells is changed. When a change of state is propagated inward toward the illuminated cells from any of the four borders



of the array, the illuminated cells block further propagation. The cells illuminated with the pattern, in effect, cast a shadow composed of residual zero-state cells.

After a programmed sequence of propagation commands, the field is tested to determine the number of cells still in the zero state. This residue depends on the pattern and on the sequence of propagation commands. If the propagation is from the left and from the top only, the residual number of zero-state cells will usually be different from the pattern derived by propagating from the right and from the bottom. By the proper sequence of commands, the classifier derives from the original pattern a new pattern also capable of blocking propagation. Tests are then conducted on the derived pattern, and further classification of the original pattern is made on the basis of these tests.

Although the construction of the classifier can be done with present-day technology, the technique has features particularly well-suited to the arrays of microscopic elements that appear to be just over the horizon.

**PREDICTING THE BEHAVIOR OF MACHINES:** As computer applications and programs become more and more complex, the question is raised whether a machine program will really behave as expected, or whether statements made in a programming language will be interpreted by the machine the way it was intended by the programmer. Since both computer programs and languages are formal systems, the problem reduces itself to an examination of consistency and the proving of theorems in formal systems, an important subject of formal logic. Consequently, an AFCRL study program in formal logic particularly pertaining to such questions has been

established and is beginning to show promising results.

A second investigation carried out under contract examined the question of the ultimate degree of miniaturization that can be achieved. This study was limited to semiconductor components. On the basis of the analysis, there appears to be a limit to the degree of micro-miniaturization. Any attempt to make elements smaller and still maintain reliability in the system may result in a larger rather than smaller package due to the need for greater redundancy.

This limit is set by many factors—statistical variations in impurity distribution, maximum resolution of semiconductor fabrication methods, power density, and the influence of cosmic rays. The last of these is perhaps the most critical factor. The contractor study translated the limitations into a specific example. For a medium-size computer (100,000 components) with a reasonable failure rate (one month between computer failures), the minimum size of the component appears to be 10 microns on a side. This is not far from the density of devices currently in the planning stage and probably within the reach of existing techniques.

The AFCRL research program in data processing discussed thus far—the studies in biophysics, in logical networks, in microminiaturization, in simulated networks and pattern classification networks—points up the scope and variety of present-day research in computer technology in the Laboratories and elsewhere. This work over the past year or two has carried computer technology to the threshold of a new generation of data processors and techniques.

Exciting as the promise of this new generation of data processors may be, there is another aspect of computer research that promises a more immediate pay-off. This involves research into new

programming languages and problem-solving techniques. During 1961-1962 a major effort in the Computer and Mathematical Sciences Laboratory was devoted to this problem area. The goal basically is not the design of new computers, but rather the extension of the area of usefulness of the general purpose digital computers already in existence.

Many of the Laboratory's experiments associated with computer languages and problem-solving have centered around the games of chess, bridge, and battleship. This specific research will be touched upon below. Essentially, the scientists working on new programming languages want to simplify methods of communicating with the computer. This work is vital not only to reduce programming costs, which can exceed the cost of computer hardware, but also to make possible the solution of certain problems which are currently precluded by practical programming limitations.

One facet of the work undertaken is the use of advanced programming languages to permit the computer solution of various non-numerical problems. In the past few years this usage of computers has rapidly broadened. At one time computers were used almost exclusively for obtaining solutions of classical mathematical problems, but currently they also are being used or being considered for such tasks as: (a) symbol manipulation including formal differentiation, integration, and simplification of mathematical functions; (b) problem solving by enlightened trial and error searching over spaces of potential solutions; (c) theorem proving by developing new proof procedures suitable for use with a computer; and (d) automatic identification of an unknown object or event as a member of one of a number of possible categories. This latter problem is usually referred to as pattern recognition, and it is applicable to such diverse

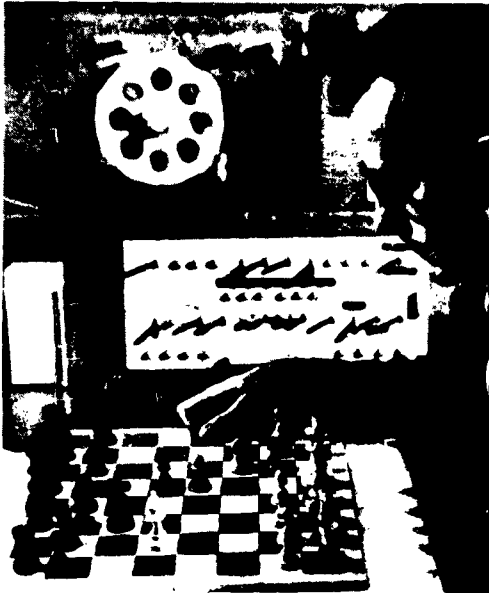
areas as printed or cursive letter recognition, spoken utterance recognition, medical diagnosis, aerial photographic target identification, and for such threat evaluation tasks as distinguishing submarines from dolphins or missiles from decoys.

In symbol manipulation, the scientists considered the use of list processing computer programming systems in the simplification of Boolean functions. Several game playing programs in the investigation of adaptive and heuristic programming were produced. These are discussed in the following sections.

#### **PROGRAMS FOR CHESS PLAYING:**

Many research programs are underway throughout the United States aimed at understanding mental decision procedures. While it is clear that mind can seldom grasp complex problems in their entirety, it can nevertheless propose one or more tentative solutions that it considers best. An excellent tool for studying and simulating these decision procedures is the game of chess, since it cannot be solved directly, and one can measure the effectiveness of various procedures by noting their success or failure against an opponent.

An AFCRL chess machine was designed to simulate as closely as possible human performance in a game. The program, written in IBM 7090 basic language for speed and minimum storage usage, looks at a given position of the pieces and considers which pieces can capture or protect others, where each piece can move, and which side has greater control of the board, particularly around the kings. This is done by constructing lists of these attributes of the pieces and squares. Using these same lists, moves are made which are considered logical (pushing pawns, capturing the opponent's piece or moving into position for a future capture, moving a piece that is in danger and also protecting and



A computer can be instructed to play a competent — if very slow — game of chess if it examines in detail every possible move several moves in advance. AFCRL is attempting to reduce the amount of computer time required for each move.

blocking against a capture, and attempting to gain control around the opponent's king while protecting your own). After a trial move, the lists are updated, and an evaluation is made based on relative dead strength (i.e., exchanges are considered in giving a piece any value), relative piece strength, relative control of entire board, and control around each king. After these logical trial moves have been evaluated, the best five (this is variable at the operator's discretion) are selected for further study. Answering moves are then considered and the process continues. The game goes three moves deep (this is trivial to change) after which minimaxing is done to arrive at the best move. Thus in order for a move to be the best move, it must first be considered as worthy of further study. It must be a move which stands up best

against the opponent's counter moves. Unlike other chess playing routines, every possible move is not considered in depth. Stupid moves are looked at only very briefly. This is a considerable improvement over past attempts along this line because the program follows human reasoning more closely, and it is faster and much shorter.

The computer program which began in January 1961, originally occupied 4000 words of storage exclusive of input-output routines, took from 10 to 15 minutes for the last five moves, 30 minutes for the second move, but three hours for the first. Since that time speeds have been increased several times over the prototype, especially for beginning and middle games. When run eventually on the 7090, which will give a further speed increase of five, the moves will take from about one to five minutes each.

**MECHANIZED BRIDGE PARTNER:** Two independently conducted research programs at AFCRL have led to the concept of a completely mechanized bridge partner. Such a partner was not assembled during the period and may never be. Nevertheless, with techniques that are available, such a partner could be assembled assuming a useful purpose could be served. Bids of the players, including those of the computer through a synthetic voice, could be made orally. The actual playing cards would consist of punched IBM cards.

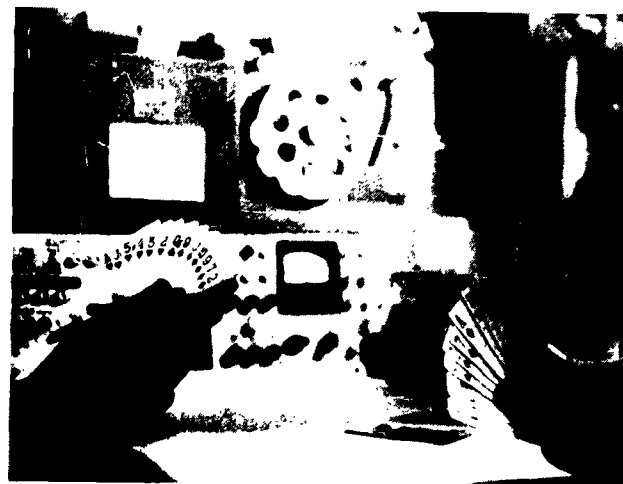
The first of the techniques making possible the mechanized bridge partner concerned computer speech recognition. Drawing on analysis techniques and special processing equipment of the Communication Sciences Laboratory, the AFCRL Cambridge Computer was programmed to accept words spoken into a microphone, to analyze the spectrum pattern of the word, and to associate this pattern with similar spectral patterns stored in memory. Once the association

is made by the computer, it can act in several ways. It can type the word on a flexiwriter; it can translate it into another language; or it can use it as a programming input, as in the case of spoken bridge bids.

The computer speech recognition program grew out of an investigation of pattern recognition and computer decision-making capabilities. The spectrum of a spoken word is so complex that the computer is often forced to make decisions as to the word from statistical inference. From the standpoint of practical application, computer speech recognition may be somewhat unrewarding because of the possibility of excessive demands on computing time and storage. These demands, for example, limited AFCRL's Cambridge Computer to a vocabulary of only 83 words. The machine can recognize words with close to 100 percent reliability, if the speaker is the same individual used to "train" the computer initially. The reliability deteriorates depending on the extent to which the pitch, enunciation and general voice quality differs from the original speaker.

But such a vocabulary is adequate for bridge bidding. Outside AFCRL relatively little research effort has been expended on the game of bridge in comparison to other games such as chess and checkers. Bridge play, however, provides an excellent vehicle for research in machine learning and in pattern recognition. Specification of arbitrary bidding conventions furnishes a good subject for the development of a convenient problem-oriented language.

The suggested AFCRL mechanized bridge partner is designed for an IBM 7090. Under the proposed bridge playing scheme, IBM cards appropriately marked as playing cards would be shuffled and dealt to three human players and an IBM 7090. The computer's cards



Bridge is an ideal game for evaluation of machine decision-making. To date, AFCRL has concentrated on the bidding aspect of bridge. Future work will concern the actual play of the hand.

would be placed in the card reader and loaded. Declarer then speaks his bid into a microphone and the bid would be recognized by the computer in real time. At the computer's turn it would communicate its bid either by flexiwriter or by synthetic voice to the other three participants. Upon termination of bidding, play proceeds with choice of cards being vocally spoken to the computer. As in the bidding, it responds in its proper turn until play is completed.

AFCRL scientists have completed work on the bidding aspect of bridge playing, and work on the playing phase of the game was in process at the close of the period. For programming, a very convenient source language is required. A large glossary of bridge terms and an easily specified system for using them are necessary (both in recognition of the relevant generalized situation and in the detailing of the indicated appropriate response). The MIT LISP 1.5 list processing language was chosen for its suitability in this application. A slightly

modified version of this language is being used for manipulation of the many bridge terms already defined for bidding.

In the "declarer learning phase" the computer is given a sequence of hands and a symbolic description of an appropriate line of play for each. It categorizes the hand as a Boolean function of a set of descriptive features and stores the appropriate responses. This will be done for the play of individual suits as well as for the choice of order of suit play.

In actually playing, the computer looks up a list of possible suit plays which have previously been described to it and notes restrictions as to orders of attacking the various suits. It then puts together sequences of reasonable plays to make up complete descriptions of play. For each such description a probability computation is made to determine the overall attractiveness of that line of play. The description affording the greatest chance of success is used to control subsequent play.

Bidding is a somewhat more tractable problem. Bridge bidding is not a good subject for a heuristic approach and is better treated as a large table-lookup procedure. Nevertheless, no bridge book exists which defines a mutually exclusive and collectively exhaustive set of bidding rules. Instead, they treat idealized situations which sometimes overlap and often leave large gaps corresponding to borderline decisions. Pattern recognition can be used in these cases but AFCRL preferred to precisely fill in holes and eliminate overlaps.

Again the MIT LISP 1.5 System was used and two separate bidding systems were treated, a natural system and the highly artificial Roman Club System originated and used successfully by Belladonna and Avarelli of the Italian bridge team. Specification of a good bidding system proved to be more volum-

inous than was expected. Individual bridge functions were extremely easy to code but not so easy to define.

**BATTLESHIP:** Many research problems in artificial intelligence require extensive investigation for potential solutions. The set of heuristic rules to follow during the investigation depends not only upon the nature of the research problem, but also upon the searcher's *a priori* knowledge of the distribution of solutions.

Typical of such problems is the game of Battleship. Any reasonable Battleship searching strategy should make use of relevant probabilities, but it should also exhibit adaptive behavior to permit the use of observed similarities in an opponent's placement of ships. One such strategy has been formulated and programmed for the AFCRL Cambridge Computer.

A number of studies have been conducted to determine the effectiveness of the various computer programs as compared to that of human competitors. In the first of these, four sets of four games each were administered to 11 subjects. In one set the ships were randomly distributed, and the other three sets contained biases of types the computer could detect. Eight computer trials using different methods and random selections in the case of equally probable choices averaged 37.56 shots per game as compared to 40.08 for the 11 subjects. From a set of only four games, however, little if any learning was observed from either subject or computer.

A single sequence of 12 games was consequently made up with similar biases common to all of the games. The subjects discovered and made use of similarities which were neither planned nor recognizable by some of the computer programs and yet they averaged 40.05 shots as opposed to 35.21 shots for

the computer. Furthermore, a distinct improvement was noticed as more games were played. For example, the average dropped from 37.50 for the first six games to 32.92 for the last six. The latter figure approached a "perfect learning" average of 31.78 shots.

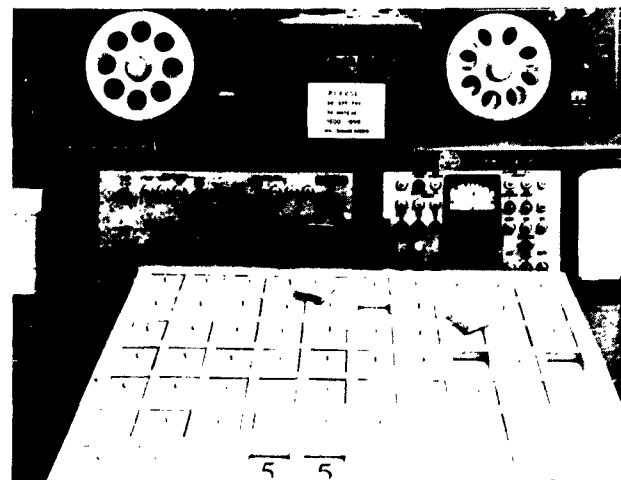
On the basis of the performance they exhibited the programs produced for Battleship constituted an interesting treatment of a problem that is considered to require intelligence.

#### **INFORMATION PROCESSING, TRANSFORMATION AND TRANSMISSION**

During the 1961-1962 period the Cambridge Research Laboratories conducted scores of individual studies relating to the processing, transformation and transmissions of information. Much of this work was highly theoretical and was carried out under such titles as information theory, communications theory, modulation and detection theory, error correcting coding and circuit network theory. In some cases the work progressed beyond the mathematical and theoretical stage to the design and bread-board implementation of communication devices.

The goals of these studies, conducted by the Communication Sciences Laboratory and by industrial and university scientists under AFCRL contract, are to achieve more efficient and effective use of available spectrum space, transmitted power and communication equipment. In general, these studies sought an optimum matching of modulation-detection configuration to information source, transmission medium and interference characteristics.

**COMMUNICATION THEORY:** Theoretical studies in communications have proceeded along several broad fronts: application of coding to the attainment of known channel capacities, optimization of modulation and detection for



In the placement of "ships" on the board, certain subtle biases, or tendencies to place the ships in a certain way can be discerned by the computer. By using this knowledge, the computer reduces number of shots needed to destroy the opponent's fleet.

fluctuating channels, matching of sources to channels, choice of modulation and detection for bandlimited channels with unusual delay characteristics.

Theoretically, error-free transmission can be made at rates many times as large as those currently achieved in practical systems. The large gap between theory and practical application results in large part from the fantastic complexity of the coding and decoding apparatus originally thought necessary for channels.

Recently, however, the gap between theory and practice has been breached in certain applications. Methods have been found which may lead to significant advances. Notable among these are the use of matrix codes which, because of certain highly desirable geometric properties, offer the possibility of very simple decoding and the use of cyclic codes which, because of desirable algebraic properties, open up entirely new decoding possibilities. A significant study on the theory of coset equivalence in group

codes established methods of classifying the properties of these cyclic codes, and recent work on the use of information sets in decoding shows great promise for decoding by a generate and compare method.

Another method of attack in the attainment of channel capacity involves the use of both halves of a communication link for transmission of information in a given direction rather than treating a two-way communication link as a pairing of unidirectional links. One fruitful way of making maximum use of both halves of the circuit is an elaboration of an old teletype technique. At the transmitter a large number of parity check digits are added to a block of information digits. These parity check digits are added in such a way as to offer as many tests as possible on the validity of the received digits.

At the receiver the corrupted digit stream is checked by means of the parity checks to find out how many errors probably occurred in transmission. If the number of errors is small, the errors are corrected by means of the inherent error-correction properties of the added parity checks; if the number of apparent errors is so large that reliable error-correction cannot be guaranteed, the receiver requests a repeat of the entire block.

The method appears to be particularly applicable to those circuits which are "good" most of the time, but which are plagued by occasional complete dropouts of signal. By suitable choice of number of information and check digits in each block, the average transmission rate on such a circuit can be made to compare favorably with the theoretical limit, and yet guarantee a probability of less than one in a billion that an erroneous message will be accepted—even in the complete absence of signal.

Transmission of information over fading circuits has become of increased

importance to Air Force communications. Future transmission problems open up the possibility of fading transmission paths via moon reflections, via scattering from orbital chaff belts, and by communication through auroral zones. Recent studies have indicated how best to detect such fading signals. It has been shown, for instance, that for a certain class of fading circuits, if sufficient spectrum occupancy is allowed to the transmitter, essentially error-free communication can be achieved below a certain transmission rate no matter how small the coherence bandwidth of the circuit, and no matter how fast the fade rate.

Another goal of the AFCRL research is the accomplishment of efficient transmission over such circuits as telephone lines which are inherently bandlimited, and may often have extremely undesirable phase-delay characteristics. The attack on this problem is twofold: attempting to find alphabets of waveforms which will permit detection by conventional means, and, in such cases where this cannot be achieved, attempting to find the optimum probability computing detector which makes maximum use of the past information received over the channel. Solutions to both of these problems have been achieved for certain idealized cases, and strenuous efforts are being made to extend the results to real-life channels.

In addition to analytical studies, AFCRL plans to synthesize many of the coding techniques on a special purpose computer to obtain statistical data, optimum design analysis, and simulated performance data. The device to be used for this is called a Logical Processor for Communications; expected delivery date to AFCRL is early in 1963. The Logical Processor is intended as a flexible analyzer-synthesizer for optimization of communication techniques including coding, modulation-detection, synchroniza-

tion, speech analysis, medium effects, and adaptive control.

Much of the more generalized work on communication theory is relevant to the specialized field of speech analysis and processing. The Communications Sciences Laboratory speech research program consists of two parts. First of all, Laboratory scientists are interested in the psychological, physiological and neurological mechanisms associated with speech generation. Secondly, they are interested in processing voice signals for transmission over low data-rate channels and over greater distances with high reliability. Particular emphasis has been devoted to attaining high intelligibility, natural quality, and preservation of the ability for listeners to recognize familiar talkers.

**QUALITIES OF HUMAN SPEECH:** Of the several major aspects of human speech, voice pitch is of particular interest. Pitch gives to speech a good deal of its emotional coloration. As AFCRL researchers have discovered, this coloration often imparts a meaning to voice communication that is more informative than the words themselves. Another reason for the special interest in pitch is the fact that compressed speech may acquire a reedy quality, and the understanding of pitch characteristics may help in overcoming this degradation of synthesized speech.

Following a lengthy analysis of some 7500 voice samples using an IBM 7090 computer, AFCRL scientists have suggested an explanation for the peculiar quality of synthetic speech and at the same time have contributed to an understanding of the mechanics of speech. It was found that in the fundamental excitation rate of speech there are often very rapid, quasi-random fluctuations. These fluctuations were found to contribute to the special quality in the voice of a given speaker, and furnish acoustic clues to the speaker's emotional state.

The extensive computer analysis of speech during 1961-1962 uncovered several interesting facets of these fluctuations. From one excitation period (roughly 8 milliseconds) to the next there was no correlation, but there was a strong correlation between the odd periods—that is, between every other excitation. An important question that the study raised was whether the pattern of fluctuations differ from person to person. If they are common to all speakers they can be built into speech synthesizers at the receiving terminal. If they differ from person to person, then the unique pattern of fluctuations of each speaker must be transmitted at the expense of additional bandwidth to assure high fidelity.

Those attempting to understand the mechanisms of speech continually encounter phenomena caused by voicing—that is, the vibration of the larynx. The controlling forces and movements of the vocal cords, however, are not completely understood. One of the reasons is that it is extremely difficult to observe their operation.



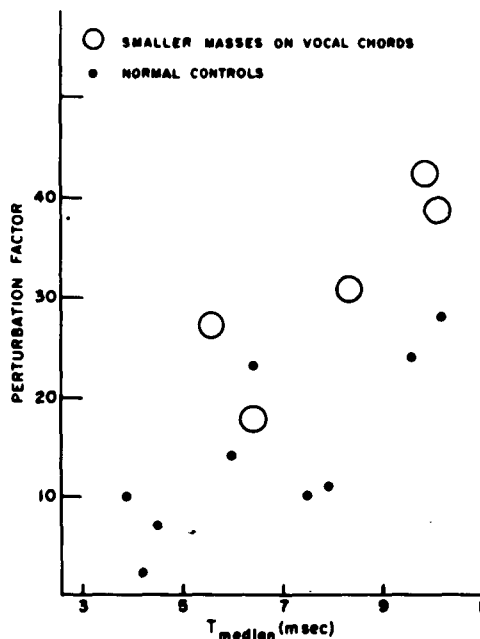
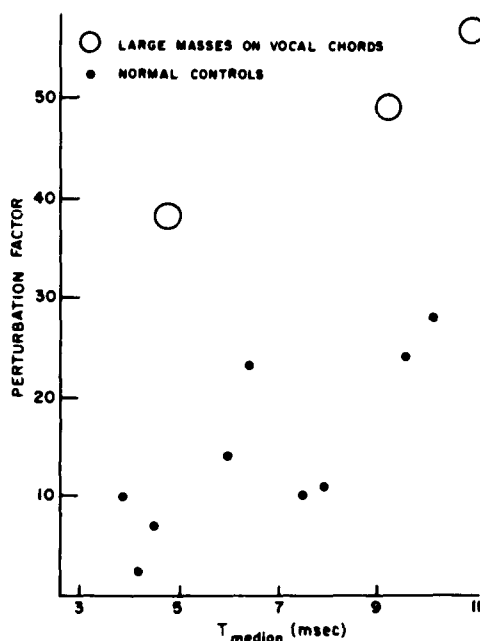
Taped voices of persons with known diseased larynxes were furnished AFCRL. Pitch perturbations in the voice signals of those with diseased larynxes are distinctly different from normal perturbations.



The best method for making such observations is to photograph the vocal cords with a high-speed camera. Such a camera is an important part of AFCRL's speech research instrumentation. A high-intensity light source, with suitable filters to eliminate both the infrared and ultraviolet portions of the spectrum is directed down the throat and reflected onto the vocal cords by means of a laryngeal mirror placed at the back of the mouth and the camera is focused on the vocal cords using this same mirror. In this way it is possible to get very good pictures of the motion of the vocal cords under various driving conditions. If the external acoustical signal is picked up with a microphone, and if, in addition, a suitable vibration pickup is placed on the throat at the front and immediately below the thyroid cartilage, these two signals may be recorded at the same time as the movies are made and correlated with the film.

As a by-product of the computer analysis of human speech signals, an AFCRL scientist during the period developed a new technique for the early detection of diseased larynxes. This technique involved an analysis of the pitch component of speech and the factors involved in pitch generation—the vocal cords, the variation of air pressure within the vocal tract, and muscular tension. To check out this research the assistance of the Washington Hospital Center in Washington, D. C., was solicited. The Center subsequently furnished AFCRL the taped voices of 32 speakers with known pathological disorders associated with the larynx.

The voice signals of these 32 speakers, together with signals of healthy speakers serving as controls, were subjected to extensive computer analysis. The results showed that disorders associated with the larynx could be detected with a markedly high degree of reliability. Several scientific papers containing the



The presence of large masses on the vocal cords is easily diagnosed, as the data on the first chart shows, but even small masses (second chart) result in a departure from the normal linear distribution.

results of this research were presented by AFCRL. Under an expanded future program, a much larger sampling of speakers will be examined.

#### **DIGITAL VOICE COMMUNICATIONS:**

The second major phase of the in-house speech research program concerns studies of the problem of digital voice communications. During the period AFCRL assembled several new major equipments to form a special and, in many respects, unique research facility devoted to digital voice communications. These new equipments are based on design concepts arrived at over a period of several years from studies of speech processing, and computer processing of voice signals.

The special facility was built around a high-performance vocoder system—an equipment which can be used to convert speech signals into digital form for transmission. At a receiver the digital signals are used to reconstruct a voice signal, which is reproduced synthetically. AFCRL vocoder research has achieved significant results in making vocoder speech more intelligible, more natural-sounding, and capable of being transmitted at significantly lower bit rates (less transmission bandwidth) than heretofore possible. The objective is to arrive at a flexible digital voice transmission device which would permit a military user a choice of a number of alternative data rates for voice transmission ranging from a "high fidelity" voice channel capability at several thousand bits per second to a transmission mode at several hundred bits per second. The military user could select an appropriate transmission mode (and corresponding data rate), in accordance with the communications channel available to him for speech transmission.

Significant progress was made towards implementing this concept of a poly-modal digital voice transmission method.

After the design concepts of a poly-modal vocoder system were established and validated through the in-house research studies, a contract was let for construction of four experimental poly-modal vocoder systems for further study and evaluation. These equipments are scheduled to be completed about January 1963.

Although AFCRL research studies have led to techniques for operating a vocoder at a data rate as low as 1200 bits per second with useful speech intelligibility and quality, a more sophisticated level of signal processing is required in order to reduce the data rate below this figure. To accomplish this an approach was evolved based on speech pattern coding.

To achieve this pattern coding, the scientists designed a special-purpose voice data processor which was placed in operation during the summer 1962. With this processor, AFCRL is able to obtain additional descriptive data quickly and efficiently, and to obtain answers to basic questions about the features of speech-signal structure that are of importance



A special speech data processor is used for the analysis of voice signals to determine an optimum set of patterns of the voice sounds which go into the makeup of individual words.

to listeners. An analyzer compares a talker's voice signal with a stored set of patterns and makes decisions, pattern by pattern, by matching the talker's pattern against the memory store. The information that is transmitted in digital form consists of the pattern numbers, and the talker's pitch information. At a receiver the numbers operate on a similarly structured memory to retrieve the explicit patterns, from which the voice is reconstructed.

The speech processing facility can perform an analysis of signals in real-time, compiling a catalog of the speech patterns of a voice signal as rapidly as the voice signal is fed into the data processor. Analysis of this kind is being performed on a variety of speech signals from a large number of talkers, and for different types of spoken languages, such as connected speech, conversational speech, word lists and nonsense syllables. As the analysis and studies of this data continues in the future, a comprehensive statistical description of voice signals will be established.



At this console, the speech signal can be altered in an infinite number of ways to determine which elements are most essential to intelligibility.

One of the novel features of the voice data processor is the capability for "stretching" speech in time. The result is an effect of "slow-motion" speech in which it is possible to hear with great acuity the acoustical detail of the successive vowels and consonants of speech, revealing sources of distortion and speech degradation that are obscure when speech is reproduced at the normal rate.

Speech quality is often a subjective value. It is often necessary to know the way listeners respond to voice signals. AFCRL researchers have almost unlimited control in modifying or standardizing a speech event in order to explore the pitch or inflection pattern of speech, the intensity or loudness, and the detailed structure of different sounds. In this way the speech signal can be manipulated to generate speech sounds for presentation to teams of listeners. From these studies with human subjects, the Cambridge Research Laboratories hope to find out how different attributes of the voice signal affect the intelligibility, quality and naturalness of the synthesized voice signal.



Quality of speech is ultimately a subjective judgment. In this room subjects listen to processed speech and evaluate its quality.

**Q**

The leading center in the Department of Defense for sounding research and technology, AFCRL's Research Instrumentation Laboratory has pioneered in the design and development of large high altitude balloons capable of prolonged flight, and of various aerospace probe devices. The Instrumentation Laboratory has played a significant role in many projects pursued by the other Air Force Cambridge Research Laboratories. During 1961-1962 more than one hundred balloons were flown by the Laboratory. Some 80 types of scientific experiments were designed and integrated aboard Air Force planes, missiles, satellites and balloons. A highlight of the work of the Laboratory during the period was a series of record-breaking balloon flights (up to 30 days), and the flight of one of the world's largest balloons which sailed across the United States at an altitude of 120,000 feet carrying a payload of one ton.

**BALLOON RESEARCH AND  
DEVELOPMENT**

To meet the scientific and operational needs of the Air Force, and also to provide support to DASA, the Armed Forces Special Weapons Project and NASA, the Laboratory for many years has conducted balloon test and launch operations at Holloman Air Force Base, New Mexico;\* Chico, California, and various

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\* Since 1954 AFCRL has had overall responsibility within the Air Force for development of new balloon systems. On 1 January 1961 the Balloon Branch at Holloman, including its test programs, facilities and resources, became a part of the Research Instrumentation Laboratory.

other temporary sites in the U. S. and around the world. Besides its important operational programs, AFCRL efforts have been directed towards increasing balloon capabilities in general, as well as designing vehicles to meet specific needs. The latter has involved an in-house and contractual research program in materials, launching devices, flight instrumentation, safety, heavy-load applications and flight analysis.

**BALLOON DESIGN:** During the reporting period the Laboratory's most recent balloon design and development efforts culminated in a remarkable series of balloon flights which demonstrated improved flight capabilities and design reliability. These flights involved 34-foot diameter superpressure balloons manufactured of Mylar,  $1\frac{1}{2}$  mils (0.0015 inches) thick in a two-layer lamination. The balloons carried 50-lb. payloads consisting of a variety of measuring instruments which telemetered data to ground stations.

On 26 April 1962 one of the new superpressure balloons, launched from AFCRL's Chico, California site, flew for 11 days at a constant altitude of 70,000 feet before returning to Earth near Cedar City, Utah. On 31 May a second superpressure balloon was launched from Bermuda and travelled westward for 19 days at an altitude of 68,000 feet. It was brought down by command while it was off Iwo Jima in the western Pacific. The 19-day flight was eclipsed shortly afterwards with the launching of a third balloon from Bermuda on 10 June. This balloon, flying at an altitude of 66,000 feet, remained aloft for 30 days before it was brought down by a pre-set timer at a point 1,200 miles northwest of Honolulu in the Pacific.

The flight-duration of superpressurized balloons is limited only by the useful life of the Mylar material used. Such



Balloons furnish AFCRL with versatile and economical test beds for carrying instrument packages above all but a fraction of the atmosphere. AFCRL has pioneered in balloon technology. The launching of these giant high-altitude balloons is an exacting task.

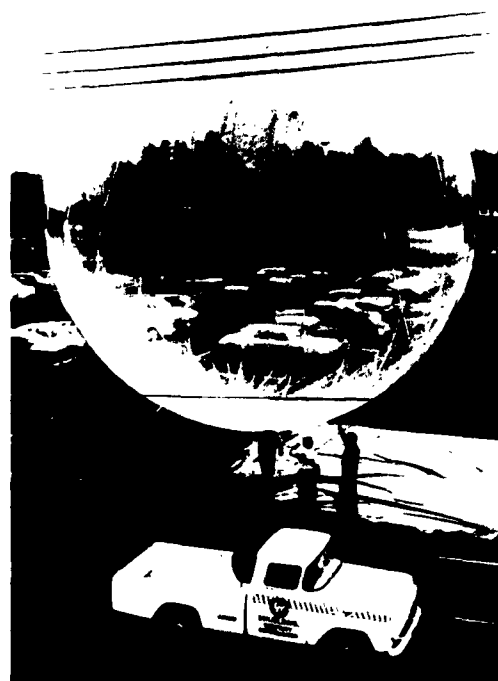
balloons may remain aloft for months and even years. The superpressure principle, in which the balloon maintains a constant volume with internal gas pressure varying diurnally, makes it possible for the vehicle to maintain a constant altitude without the use of ballast. The need to carry the latter, to compensate for the nighttime descent, sets a limit on the flight duration of conventional balloons. The 1962 series of AFCRL flights successfully demonstrated that in the superpressure balloon, scientists possess a new research tool for making long duration observations at high altitudes.

Earlier, the Research Instrumentation Laboratory had also recorded an important success in flying a 300-foot diameter balloon of a new design. Nearly 12 million cubic feet in volume, it was the largest plastic balloon ever flown. The balloon was launched from Chico on 24 October 1961 and flew at an altitude of approximately 120,000 feet carrying a 2000 pound payload of instruments (telemetry equipment, an upward looking motion picture camera to study balloon deployment), and fine steel dust as ballast.

The objectives of the test were to determine the adequacy of the balloon structural design and to study the ballasting characteristics of high altitude heavy payload balloon systems. The entire system performed well and analysis of the flight profile indicated no problems with gas leakage—a significant fact considering that the surface area of the balloon was nearly seven acres and the thickness of the balloon wall was only 0.001 inches. The balloon flew from California across the northern part of the U. S., the flight being terminated by radio command 51 hours and 10 minutes after launch at a point over the Atlantic Ocean approximately 200 miles east of Boston.

During the period the Laboratory also successfully designed and developed balloon vehicles for the Aeronautical System Division (five flights carried payloads of 400 to 800 pounds to altitudes above 120,000 feet), and one for the Space Systems Division (six successful flights with payloads up to 1200 pounds). In addition, the Laboratory pursued the development and evaluation of a balloon platform for Project Stargazer, which involves lifting a 3,600 pound manned astronomical gondola to an altitude of 85,000 feet.\*

\* Project Stargazer is discussed in Chapter VII.



Prototype of the record-shattering 34-foot diameter superpressure balloon which flew 30 days at a constant altitude of 66,000 feet is pictured. The balloon was launched from Bermuda and was destroyed over the Pacific Ocean 1200 miles north northwest of Honolulu one month later.

Besides the above, the Research Instrumentation Laboratory served as an adviser on balloon designs on several projects, including a planned flight and recovery of an unmanned telescope with a Tufts University stabilization and pointing control; a flight of a John Hopkins University astronomical experiment; and a Princeton University program involving the flight of an exceedingly delicate 36-inch telescope.

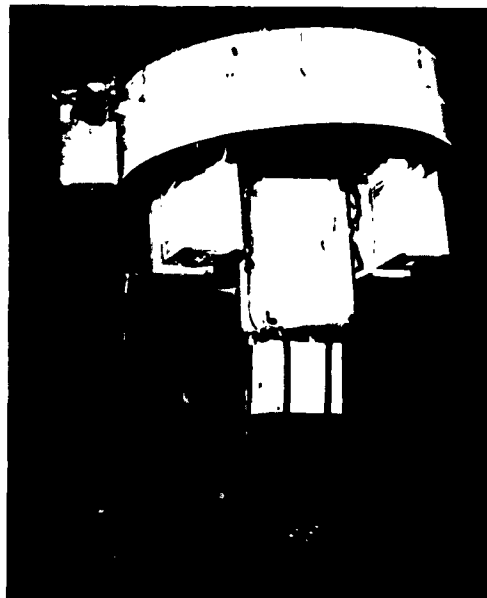
**BALLOON DEVELOPMENT:** The trend of balloon development during the period was towards lifting heavy payloads in the 3,000 to 10,000 pounds range to altitudes of from 60,000 to 120,000 feet. In this connection, AFCRL flight tests of 5 million cubic foot balloons of a new capped design were successfully conducted, carrying payloads of 3000 pounds to 100,000 feet. Since the design showed promise for lifting greater payloads, additional work was begun using the same design principle. It is planned to employ a balloon made of 1.5 mils thick polyethylene for a flight of a 5,000 pound payload to 80,000 feet. For heavier payloads, the Laboratory plans to design a polyethylene balloon using a fabric reinforced top, to be tested for flight of 8,000 pounds to an altitude of 60,000 feet. In both programs one of the objectives is to obtain a high payload capacity balloon vehicle of low cost.

AFCRL research involving both high strength plastic films and reinforced plastics is to be continued with design, fabrication, and flight tests of several such balloons. The use of high strength materials is expected to increase maximum balloon payload capabilities. With currently available materials, payload capabilities in the 15,000 to 20,000 pound range can be reasonably expected. However, one limitation, as indicated, is cost since such balloons may be prohibitively expensive for small scientific programs.

The Research Instrumentation Laboratory holds that, once developed, capped balloons will provide a reasonable solution in both cost and maximum payload capability, as between a fully reinforced balloon and an unsupported polyethylene plastic balloon vehicle.

During the period an AFCRL investigation of forces between the gas barrier and load tapes (generally fortisan or glass filament reinforcing tapes) also was continued. The purpose was to obtain a better understanding of the structure of balloons and the mechanics of failure, in order to ultimately create more efficient payload-carrying structures.

One final AFCRL balloon development investigation pursued during 1961-1962 involved a fabrication study for exceedingly high altitude balloons in the above 180,000 foot altitude range. High



Payload for balloon test is shown here being prepared for launching. This payload simulated a 3600 lb. two-man gondola to be used in the balloon astronomy program on a test of balloon reliability.

strength and light-weight films were developed experimentally which hold promise for ultimately achieving the strength-to-weight ratio needed for extreme altitude flight.

**BALLOON INSTRUMENTATION:** Paralleling AFCRL's balloon design and development was a comprehensive and continuing program to develop the necessary instrumentation for flight safety, balloon control, and the measurement of the various parameters affecting balloon operations. These instruments were required to function accurately for prolonged flight durations. The primary Laboratory effort was aimed at increasing instrument accuracy while reducing electrical power and weight requirements, to achieve reliable performance to altitudes of 150,000 ft.

During the period a complete command and control flight system including necessary ground support equipment, specifically designed for use with high-altitude extended - duration research balloon vehicles, was developed. This system was flight tested and proven under actual operational conditions during some 100 free balloon flights launched within the continental United States. The system provides for direct individual control of nine independent command functions. Command capability can be extended to 18 or more functions by incorporating serialized time sequencing on any channel. The design was especially aimed at providing immunity to extraneous noise, false triggering and adjacent channel interference, selective image rejection and cross-modulation impairment. Extreme sensitivity required for long range HF control was successfully achieved with optimum noise figures, miniaturized from factor, conservative power consumption and operational reliability

comparable to redundant systems. Many of these units were recovered and re-flown repeatedly.

As indicated in earlier chapters, an important use of the balloon vehicle is as a high altitude platform for making measurements in such fields as radiation, background noise, photography, and antenna systems. For this work it is desirable that the possible deviation of the instruments (load line) from the true vertical direction be known and recorded in flight. For any fixed payload, the balloon volume and consequently the balloon weight must be increased to reach higher altitudes. It can be expected that the swing amplitude of the payload will increase with floating altitude because of the rapid increase in ratio of the moment of inertia of the balloon to the moment of inertia of the payload (with respect to the center of mass of the balloon system). During the period the Laboratory placed under development a unit for measuring and recording the variation of the direction of the loadline in one plane with an accuracy of 0.5 minutes of arc. This device is to be tested on future flights that require platform stability information.

In another instrumentation area, to eliminate errors in direct ambient temperature measurements when thermistor beads are used, development of a temperature sensor also was pursued. The temperature errors increase at higher altitudes because of the decrease in heat capacity of the air as a function of altitude. It appeared possible to improve on the heat capacity limitation of thermistors by using very small diameter metal wires. Wires of much smaller diameter than 10 microns were desired to achieve a sufficiently low heat capacity for accurate measurement, but even 10 micron wire was extremely fragile and difficult to assemble in a sensing unit.



The new AFCRL sensor will use small quartz fibers coated with platinum or nickel. These fibers are tough and of very low heat capacity, since they may be as small as 1 micron in diameter or about 175 times smaller than the tiniest thermistor. The resistive stability of the metal coating is still to be determined. Success in this development may lead to other important sensor applications for these fibers, such as in pressure and rate of ascent indicators.

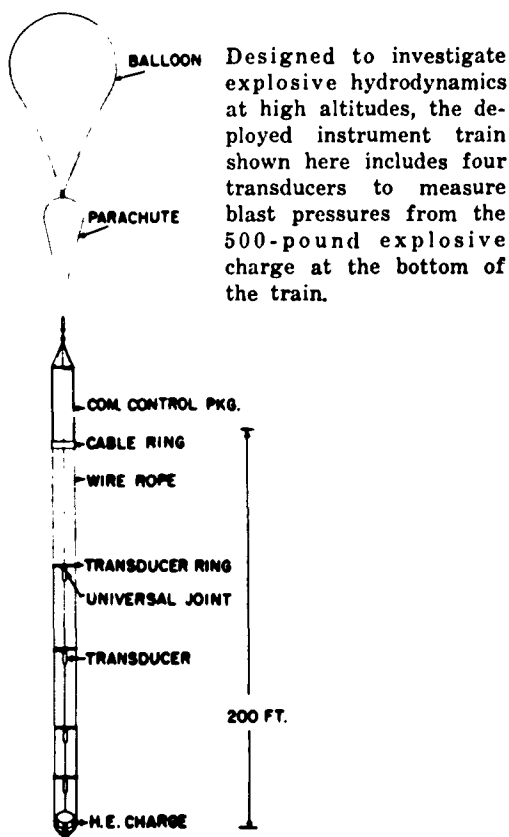
**FLIGHT OPERATIONS RESEARCH:** The Research Instrumentation Laboratory's flight operations has as one of its goals the scientific exploration of the properties of the atmosphere as a balloon carrier. During 1961-1962 continued emphasis on precision ballooning featured the main AFCRL effort in this field. An extensive series of flights for the BANSHEE (see below) and Retu programs was conducted during the summer and fall of 1961. Balloons were launched from Hobbs, N. M., Artesia, N. M. and Holloman Air Force Base, and programmed to float precisely over a specified target area at the White Sands Missile Range.

In connection with these flights, as balloons increased in size to carry heavier payloads to higher altitudes, an increasingly critical problem was encountered involving wind speed at the earth's surface and the wind shear in the lowest 800 feet. It was found that the low level jet which prevails in the Great Plains during the summer months presents an unfavorable condition for launching large balloons. This problem has become a significant factor in connection with establishing proposed launching sites for various balloon projects.

Balloon programs at the AFCRL's Holloman Air Force Base test location also included studies and operational test flights involving precision balloon tra-

jectory forecasting, wherein a balloon launched outside the range area must reach a specified point in space at a pre-selected time. Most of these efforts support missile and space developmental efforts, providing over-range infrared or radar targets for missile testing or platforms for re-entry capsule tests. At the close of the period the results of these studies and tests, as they applied to the Mexico area, were being integrated into a broader study of the problem of long duration high altitude precision balloon trajectory forecasting.

**THE BANSHEE PROGRAM:** Another aspect of the Laboratory's work involves the Defense Atomic Support Agency sponsorship of a tri-service program to investigate non-nuclear blast effects at high altitude — Balloon and



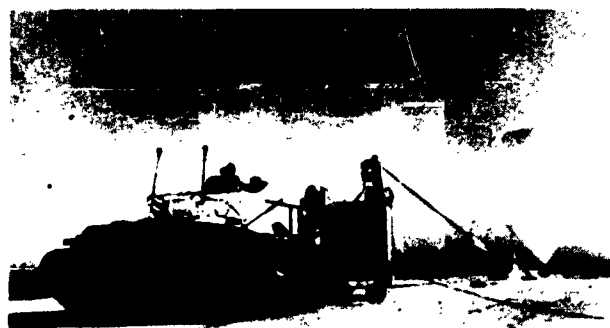
Nike Scaled High Explosives Experiments (BANSHEE). This effort consists of a series of experiments to provide data at altitudes of 38,000, 80,000, 100,000 and 115,000 feet under four specific conditions: Phase I, stationary charge and stationary measurements; Phase II, moving charge and moving measurement; and Phase III, stationary charge and moving measurement; and Phase IV, moving charge and moving measurement. The data obtained was to be directly applied to the anti-missile problem. Agencies participating in the DASA program besides AFCRL are: The Naval Ordnance Laboratory, the Army Ballistic Research Laboratory, and the Army Missile Test Center.

The responsibilities of AFCRL in this program were to: (a) develop and field test flight systems including special deployment and launch techniques; (b) develop and test a suitable ground and air-borne command-control system; (c) provide instrumental balloon flights for test of other agencies' equipment; (d) select and establish suitable launch sites; (e) provide forecast analysis and balloon flight trajectory forecasts for all flights; and (f) prepare balloons and airborne command and control equipment, launch balloon systems for all flights, establish and operate ground command-control sites.

The BANSHEE system for Phases I, II and III was designed to deploy and launch a balloon-borne instrumented train 200' in length, carrying either a 500-pound sphere of high explosives or a radar target reflector and a miss distance flare package. The operational concept called for floating a number of these systems over the White Sands Missile Range at the various altitudes, at which time the high explosives experiment is conducted.

By the end of June 1961 all develop-

ment had been accomplished by the Laboratory and a total of 22 development-test balloon flights had been made. Of particular significance during the period was the adapting to balloon launching and the introduction into the overall development program of an M-48-42 Army tank as a launch vehicle. In the interests of safety of the launch personnel, the protection afforded by this vehicle was considered essential. During July-December 1961 a total of eight operational test flights were successfully conducted. Two of these balloon flights were full scale dry runs, launched from Hobbs, N. M., and terminated while floating over the Range at 80,000 feet. Five were full scale Phase I operational runs. Three of these were launched from Hobbs and detonation was effected at 80,000 feet. One was launched from Artesia, N. M., and detonation was effected at an altitude of 100,000 feet. The fifth was launched and detonated over the range at a 25,500 foot altitude. One Phase II flight also was successfully conducted with balloon



An Army tank is used as a launch vehicle for the Banshee balloon package. When the balloon is released and rises, the tank is maneuvered underneath to provide vertical lift. The 200-foot instrument train is deployed from the rack on the front of the tank under control of a winch-line operated from the tank.

launch from the range and Nike intercept being effected at 27,500 feet.

The operational completion of Phases I and II was scheduled for the summer of 1962. Flights planned included: Phase I, one at 38,000 feet and one at 80,000 ft., two at 100,000 ft., two at 115,000 ft.; and Phase II, two at 115,000 ft. These flights were to be launched so that flight trajectories would carry the balloons over specified segments of the Range for detonations or intercept.

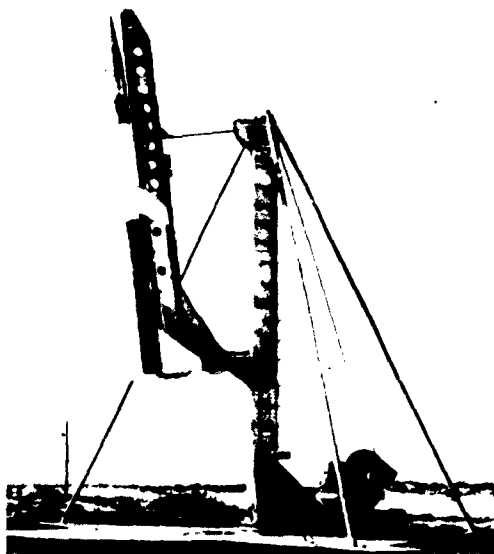
#### RESEARCH PROBE PROGRAM

The Research Instrumentation Laboratory's sounding rocket probe program has origins going back to the early post-war years when a few AFCRL personnel participated in V-2 launchings at the White Sands Missile Range. AFCRL personnel currently are responsible for some 80 scientific payloads each year,

carried on a variety of vehicles and launched from a number of different sites. The basic purpose of this research probe program is to make available to the various AFCRL laboratories in timely fashion new designs of vehicle and instrumentation.

The program includes not only the work to schedule and integrate experiments for high altitude probes, but also a continuous program of research and development to take advantages of all advances in the field of vehicles and instrumentation.

In the field of instrumentation, the Laboratory has been concerned with such devices as telemeters, tracking beacons, command receivers, power supplies, antennas, timers and programmers, plus specialized electronic devices such as solar and lunar pointing controls. Since these devices take up space and weight, which might be more profitably



Four Astrobee 200 research rockets were used during the reporting period by AFCRL scientists for a variety of experiments. The Astrobee 200 rocket can carry a 160-pound payload to an altitude of 225 miles.



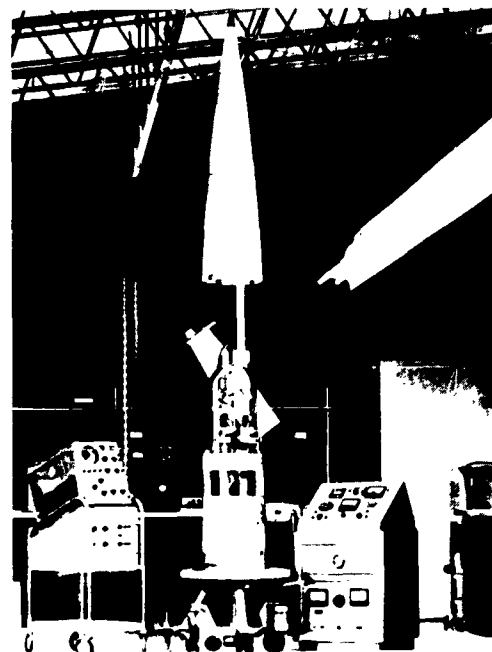
The Astrobee 1500 rocket was used by AFCRL scientists in such programs as ionospheric sounding and geodesy. This rocket can carry a 50-pound payload to an altitude of 1400 miles.

used by the basic experimental sensors, an important aim of the Laboratory has been to reduce weight, size and power consumption. At the same time, the Laboratory also has sought new techniques for making maximum use of currently available equipments, to consolidate functions and to adapt changes in range instrumentation. The above research has produced a variety of advances in the instrumentation area.

One of these is the AGA C/T-CV transistorized radar transponder designed and developed to fill the need for a space-saving C-band transponder to fit the 6½ inch diameter for the Nike-Cajun rocket. The comparison of this miniature transponder with the larger range-developed DPN-42 which has comparable performance makes the need for such a development obvious. Another is an S-Band PRF-command system, which makes possible the initiation of an "event" at a predetermined altitude within an accuracy of a kilometer or so.

In the area of rocket-probe antennas, the designer is faced with the conflicting requirement of making an efficient radiator without adversely affecting the aerodynamic properties of the rocket. In addition, the behavior of the antenna under the adverse environmental conditions such as high accelerations, shock, vibration and extreme temperatures, is of primary importance. Voltage breakdown is an ever present problem due not only to low pressures but also to the ionized conditions either present in the upper air or induced by high velocities. During the period a variety of antenna techniques for beaconry were developed to meet those needs and to provide better radiation pattern coverage, especially at the higher frequencies.

**ORIENTATION DEVICES:** In the field of orientation controls, work has been carried on by AFCRL for a number of years. The most widely known and used



Shown here is an ultra-violet experiment mounted in a pointing control for the Aerobee rocket. The pointing control utilizes photocell "eyes" around the circumference of the nose cone to direct the upper portion of the payload toward the sun in azimuth. The arm carrying the spectroscope swings out after the nose cone has been removed at altitude.

of these devices has been the pointing control for the Aerobee rocket. This instrument, which constrains the axis of an experiment to within a few minutes of arc toward the sun, has been most successful in carrying spectrographs, monochromators, etc., for studies of the solar spectrum.

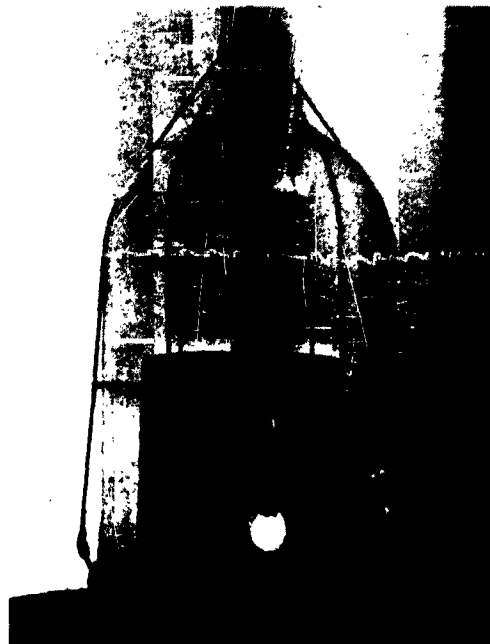
When a requirement arose to perform similar experiments on board an earth-orbiting satellite, a contract was placed for development of a new instrument. In the case of orbiting flights, more serious tracking and environmental problems had to be faced than had been encountered in the probe versions. One of the most difficult problems involved

the fact that rotating mechanisms, slip-rings, bearings, etc., which operate successfully under pressures as low as  $10^{-6}$  mm Hg, would wear out rapidly at space pressures even with the most modern of lubricants. For example, one calculation showed that even with a small nutation of twenty milliradians per second, slip-ring surfaces would be destroyed in six months. This problem was finally solved by carefully burnishing the surfaces and operating them "dry".

For use in studying X-ray emission from the moon, an adaptation of the solar pointing control also was developed under contract which will keep an X-ray spectrometer oriented toward the moon during a future Aerobee rocket flight. The major development problem here was to retain the pointing accuracy of the earlier device while working on a signal which is down by a factor of one million.

**VEHICLES:** The AFCRL probe program required not only the design of instrument packages, command systems and orientation devices, but also a continuous effort to enhance the utility and dependability of the sounding rockets themselves. The versatility of the experimental program was limited by the restrictions of the probe vehicles that were available, and therefore an important part of the AFCRL program was concerned with improving the basic experiment carriers.

In this area of vehicle improvement, the Research Instrumentation Laboratory supported the development of several new sounding rockets. Two are of special importance. The first, the Astrobe 200, has a performance level sufficient to carry a 200 pound gross payload to a height of 150 statute miles. On 3 June 1961 the first Astrobe 200 was launched at the Air Proving Ground



Corona discharge on 234-M quadraloop antenna at a simulated altitude of 20 miles is shown here. Corona discharge is one of the major problems in designing antennas for high altitude rockets.

Center in Florida, but failure of the second stage fins resulted in erratic performance. After suitable modifications were made, on 29 January 1962, a second vehicle, carrying a day-air-glow experiment as well as performance monitors, flew successfully overshooting the predicted 135 mile zenith by some 20 miles.

The second rocket, the Astrobe 1500, had a similar experience. During the first trial on 1 August 1961, there was a catastrophic failure due to first stage nozzle burn-through. The second trial on 8 December 1961 was successful, the vehicle carrying a gross payload of 85 pounds to 1350 statute miles as predicted. The payload, in addition to performance monitors, contained flares for

geodetic survey purposes.\* This vehicle was designed and fabricated by Aerojet General Corp. The Laboratory supplied the instrumentation packages and conducted the actual field test at the Pacific Missile Range.

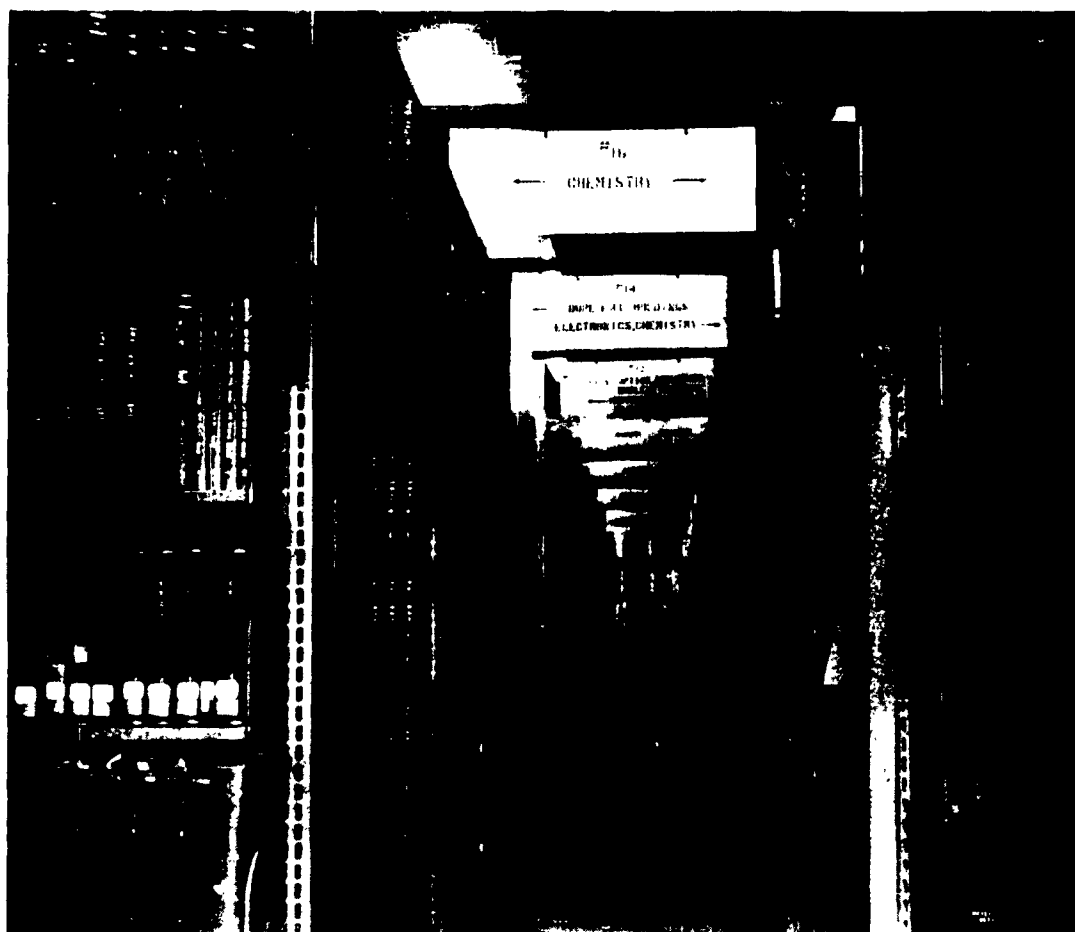
A study of the basic dynamic loads on the EXOS vehicle also was initiated during the period. This rocket requires careful design of payload and flight profile because of its extremely high speeds and accelerations. The dynamic loads study involves the formulation of a computer program to handle various effects on structure, such as inertial loads, bending moments and wind effects. In an effort to assess the efficiency of the flared skirt as a stabilizing member, wind tunnel tests on the EXOS also were conducted during the reporting period. Modifications resulting from these studies subsequently resulted in a successful EXOS flight.

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\* This experiment is discussed in detail in Chapter IV.



Seen within the heat shield is the second stage motor and payload of Astrobee 1500 being readied for launch. The shield protected the payload and second stage motor from aerodynamic heating and was ejected prior to second stage ignition.





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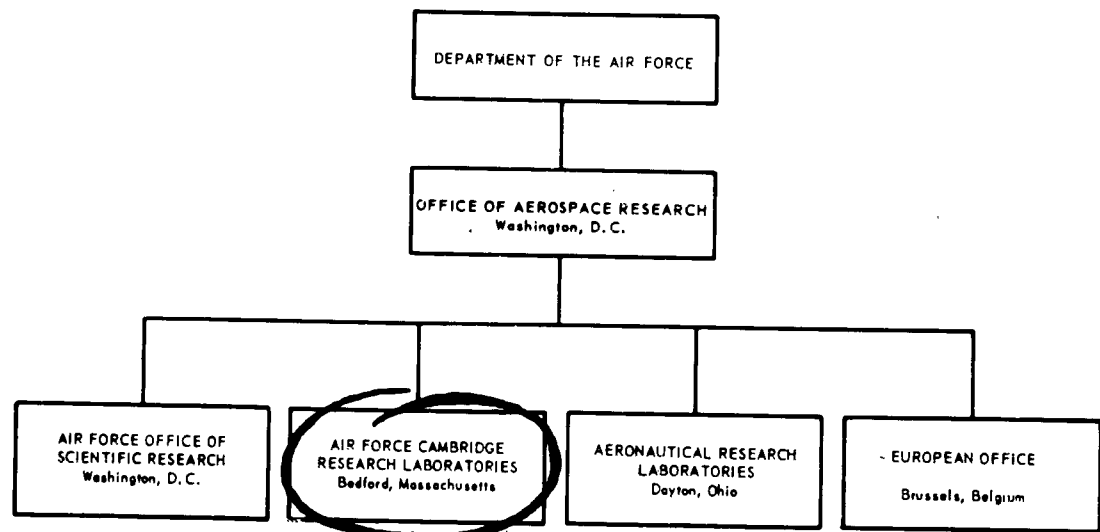
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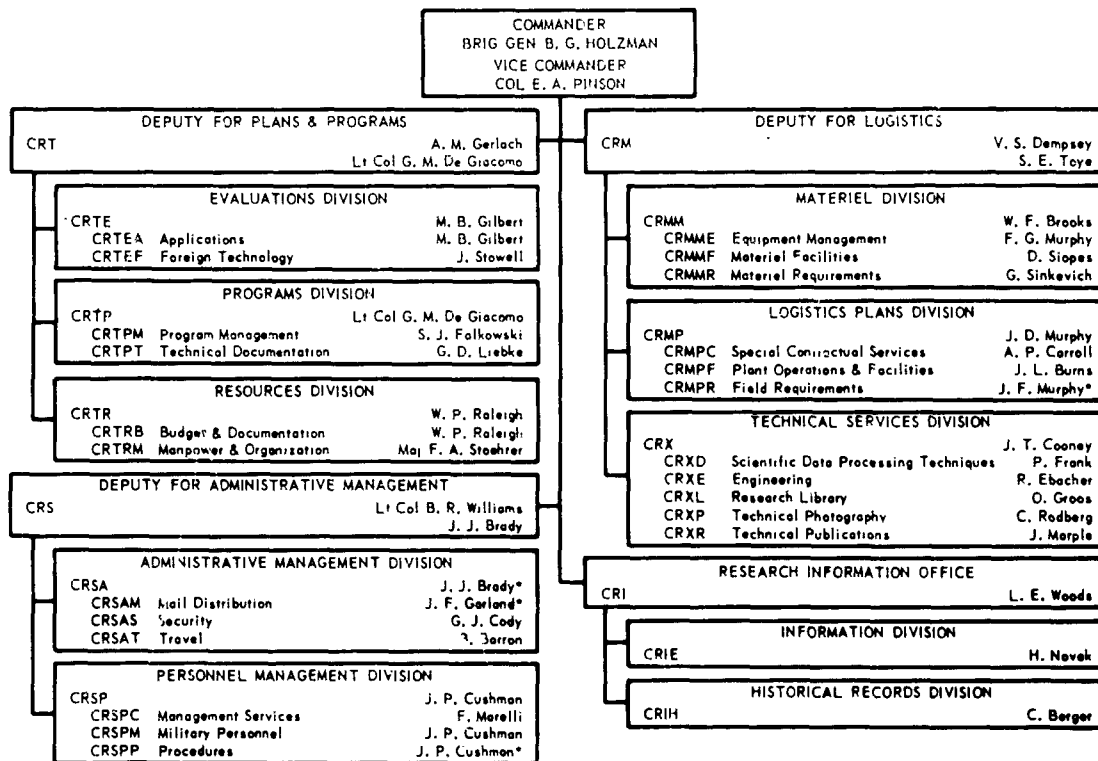
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**Appendix D**  
**Organization**

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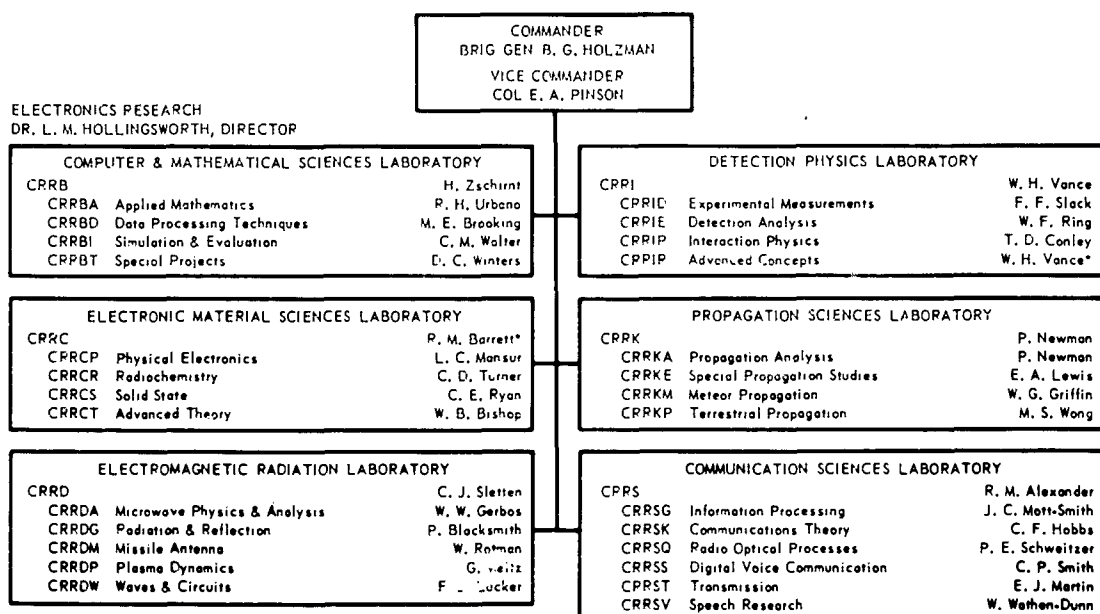


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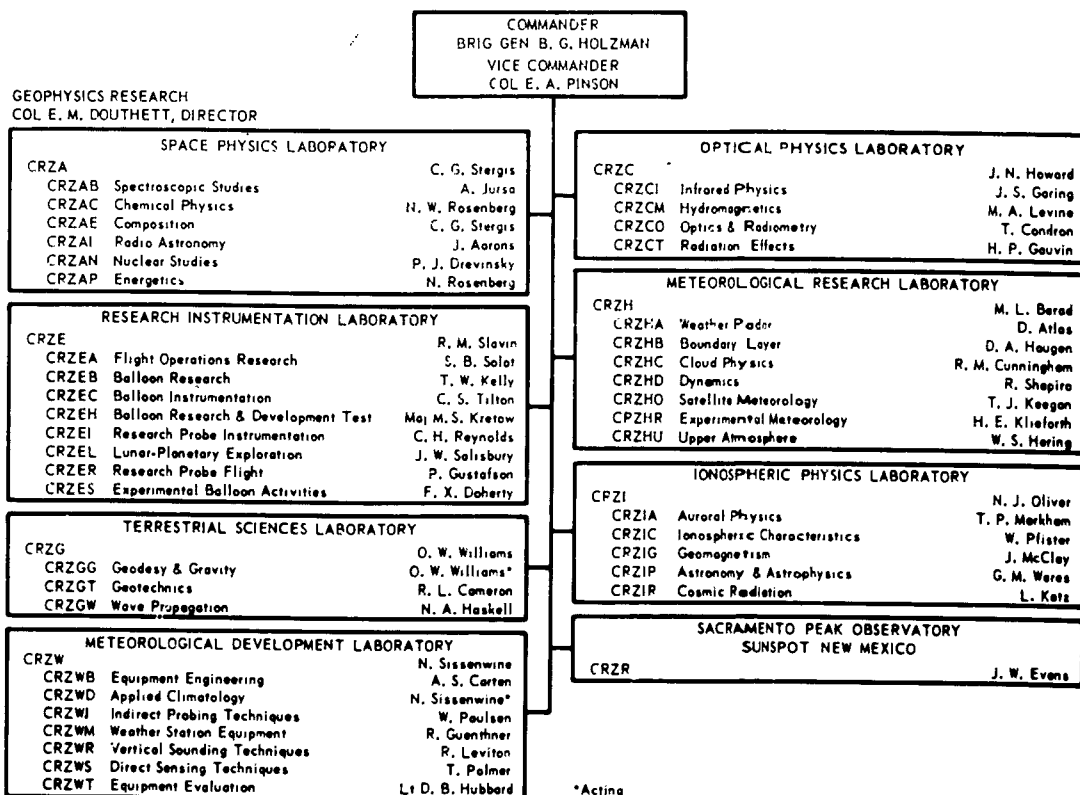
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